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Water resources of the upper Blackfoot River Valley, west-central Montana

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Prepared in cooperation with the United States Geological

No. 1

WATER RESOURCES OF THE UPPER BLACKFOOT RIVER VALLEY WEST-CENTRAL MONTANA

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by D.L. Coffin and K.R. Wilke

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Water Resources of the Upper Blackfoot River Valley, West-Central Montana

by

D. L. Coffin and K. R. Wilke

Prepared in cooperation with the
United States Geological Survey

1971

TABLE OF CONTENTS

	Page
Abstract	2
Introduction	3
Acknowledgments	4
System for Describing Geographic Locations	5
Location and Extent	6
Topography and Drainage	6
Temperature and Precipitation	8
Geology	9
Geologic Setting	9
Geologic and Hydrologic Characteristics	12
Basement Rocks	12
Tertiary(?) Sedimentary Rocks	15
Till	17
Outwash	19
Lakebed Deposits	20
Alluvium	20
Hydrology	25
Surface Water	25
Groundwater	26
Recharge	27
Water-level Fluctuations	29
Movement	30
Discharge	33

Page

Hydrology -- cont'd

Quality of Water 34

Surface Water 35

Groundwater 39

Proposed Developments Associated With the Proposed Mining Operation 40

Summary and Conclusions 44

Suggestions for Continuing Study 46

References 48

Appendix 49

WATER RESOURCES OF THE UPPER BLACKFOOT RIVER VALLEY, WEST-CENTRAL MONTANA

by

D. L. Coffin and K. R. Wilke

ABSTRACT

Proposed development of the mineral resources in the upper Blackfoot River basin has caused concern about the possible effects on the hydrologic system. This report describes the water resources of the area so that any hydrologic problems attributable to mine-waste disposal may be better understood.

Rocks in the area are grouped into six units based on gross lithologic features and hydrologic properties. Alluvium along the Blackfoot River is the most permeable unit and is of greatest importance to the groundwater system. The Blackfoot is a gaining stream between Cadotte Creek and Flesher Lakes but is a losing stream between Flesher Lakes and Lincoln. Groundwater in the alluvium flows down the valley roughly parallel to the valley walls. Groundwater flow is interrupted upstream from the mouth of Alice Creek and near Flesher Lakes by two "dams" of till and outwash.

Plans proposed by The Anaconda Company will keep water that has contacted mine wastes out of streams. The greatest chance for contamination of the hydrologic system will be by seepage of water that has contacted mine waste to the groundwater reservoir. Locations proposed for the tailings pond and most of the length of the collection ditch are on deposits of relatively low permeability. The proposed location for the clarification pond, however, is on alluvium, and more data are necessary to estimate accurately the possible infiltration rate from the proposed pond.

INTRODUCTION

Public interest in the quality of our environment raises several questions concerning development of mineral resources. Added to the age-old question of whether the development will be profitable are new questions. Will the development cause deterioration or improvement of the environment in adjacent areas? Will the amount of deterioration exceed benefits expected from the development? How can possible deterioration of the environment be minimized? Will the cost of minimization make the development unprofitable? If deterioration of the environment is to be minimized, then the natural systems and their interrelationships must be understood because changes to one system may cause unwanted changes in another.

This report is a description of one of the most basic natural systems in the upper Blackfoot River basin--the hydrologic system. The report is the result of a study made by the U.S. Geological Survey in cooperation with the Montana Water Resources Board. The Montana Water Resources Board needed information to understand better the possible effects of a proposed copper-mining operation on the hydrologic system in the headwaters of the Blackfoot River. The purpose of this study is to describe the hydrologic system so that any possible hydrologic problem associated with disposal of mine wastes can be alleviated by proper engineering design.

To describe the groundwater system, basic data were collected and analyzed. Data consist of the records of selected wells (table 6), logs of test holes (table 7), records of pumping tests (table 8), chemical analyses of water (tables 3, 4, and 5), and miscellaneous discharge measurements (table 2). These data are related to the geologic framework to help describe the groundwater system.

ACKNOWLEDGMENTS

Without the assistance and encouragement of many persons, this study would not have been possible. Douglas Smith and Ronald Guse of the Montana Water Resources Board assisted in project planning and made helpful suggestions during field inspections. Charles Potter and Gary Knudson of The Anaconda Company gave permission to drill test holes on land owned by the company and provided test-hole logs and pumping-test data from company files. John Baucus of the Sieben Ranch Company permitted test drilling and installation of water-level recorders and a streamflow station on land owned by his company. Ted Schwinden, Commissioner of the Department of State Lands and Investments, gave permission to drill on State land. Miller Hansen and Henry McClernan of the Montana Bureau of Mines and Geology visited the area and provided expert council about the geology. The test-drilling and test-pumping programs were successful only because of complete cooperation by Mort Barrus of Barrus Drilling and Pump Company and Don Martin of M. T. Drilling Company.

The assistance and encouragement of all those connected with this study is gratefully acknowledged.

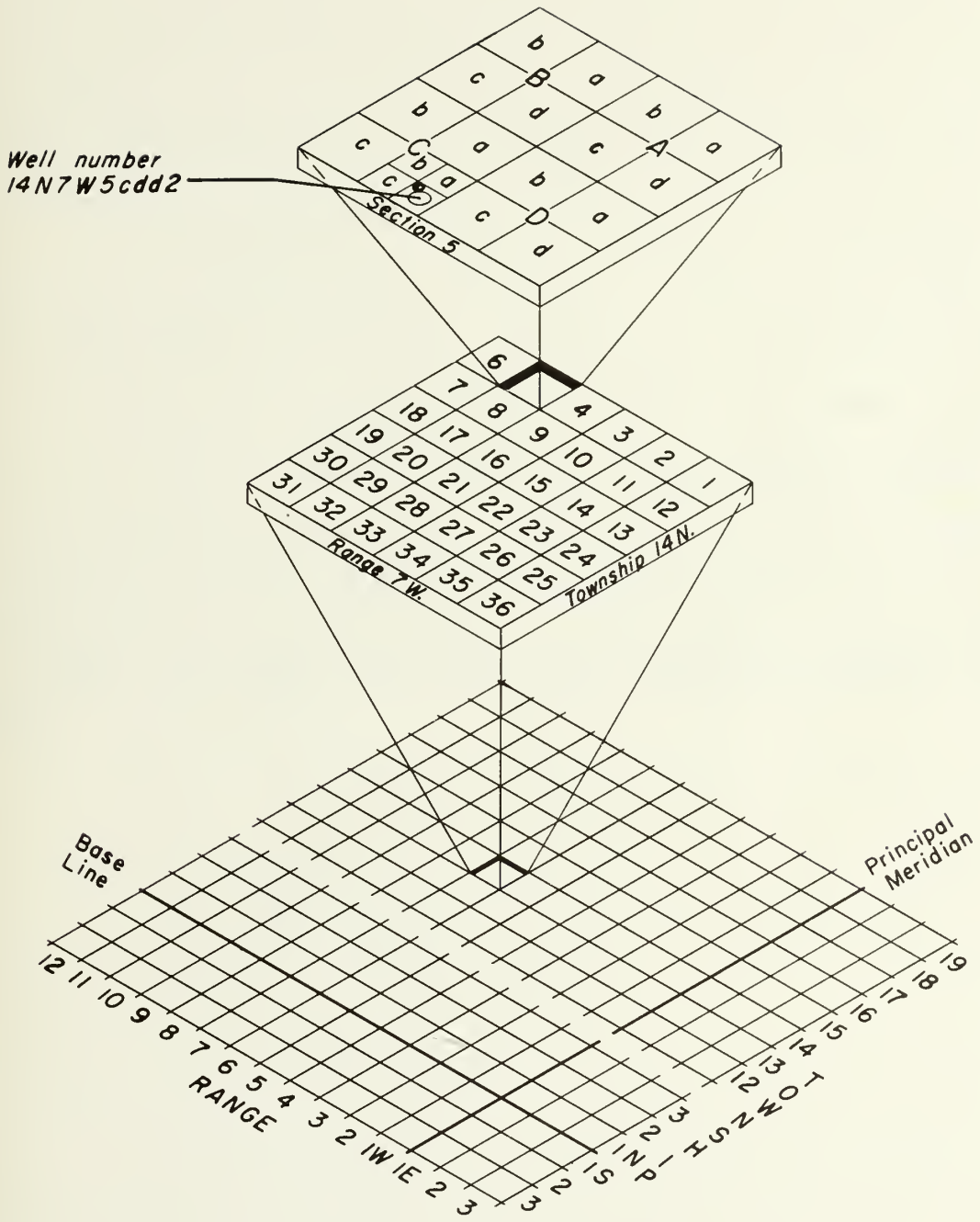

Figure 1 -- System of specifying locations.

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SYSTEM FOR DESCRIBING GEOGRAPHIC LOCATIONS

In this report, locations are specified by location numbers that may consist of as many as 12 characters, which are derived from the General Land Office system of land subdivision. The first three characters of the location number specify the town-ship, the next two the range, the next one or two give the section number within the township and the next three specify the location within the quarter section (160-acre tract), the quarter-quarter section (40-acre tract), and the quarter-quarter-quarter section (10-acre tract). Subdivisions of a section are designated a, b, c, and d in a counterclockwise direction, beginning in the northeast quadrant. If there is more than one feature in a 10-acre tract consecutive digits beginning with 2 are added to the location number. For example, a well numbered 14N7W5cdd2 would be the second well inventoried in the SE$\frac{1}{4}$ of the SE$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 5, Township 14 North, Range 7 West. This system of specifying locations is shown in figure 1.

LOCATION AND EXTENT

The study area is in west-central Montana. It extends from 3 miles west of Lincoln to about 15 miles east of Lincoln (figure 2) and contains about 66 square miles. The eastern edge of the study area is about 3 miles west of the Continental Divide. The area is in Lewis and Clark County and includes about 6 square miles of the Helena National Forest. Lincoln is the only town in the area.

TOPOGRAPHY AND DRAINAGE

The area is mountainous. Elevations range from about 4,450 feet above mean sea level where the Blackfoot River leaves the study area to slightly greater than 6,200 feet on the tops of mountains near the river. Mountains rise steeply 500 to 1,000 feet above the river. Relief is greatest in the eastern part of the area.

The Blackfoot River flows from the Continental Divide westward and joins the Clark Fork near Missoula. Near the headwaters, the Blackfoot valley is less than half a mile wide, but it is more than 3 miles wide near Lincoln. The valley floor is nearly flat in cross section. The average slope of the river valley through the study area is about 25 feet per mile.

Major tributaries to the Blackfoot River from the north are, in downstream order, Pass Creek, Cadotte Creek, Alice Creek, Landers Fork, and Keep Cool Creek; major tributaries from the south, in downstream order, are Willow Creek, Hogum Creek, and Poorman Creek. Except for Cadotte Creek the major tributaries

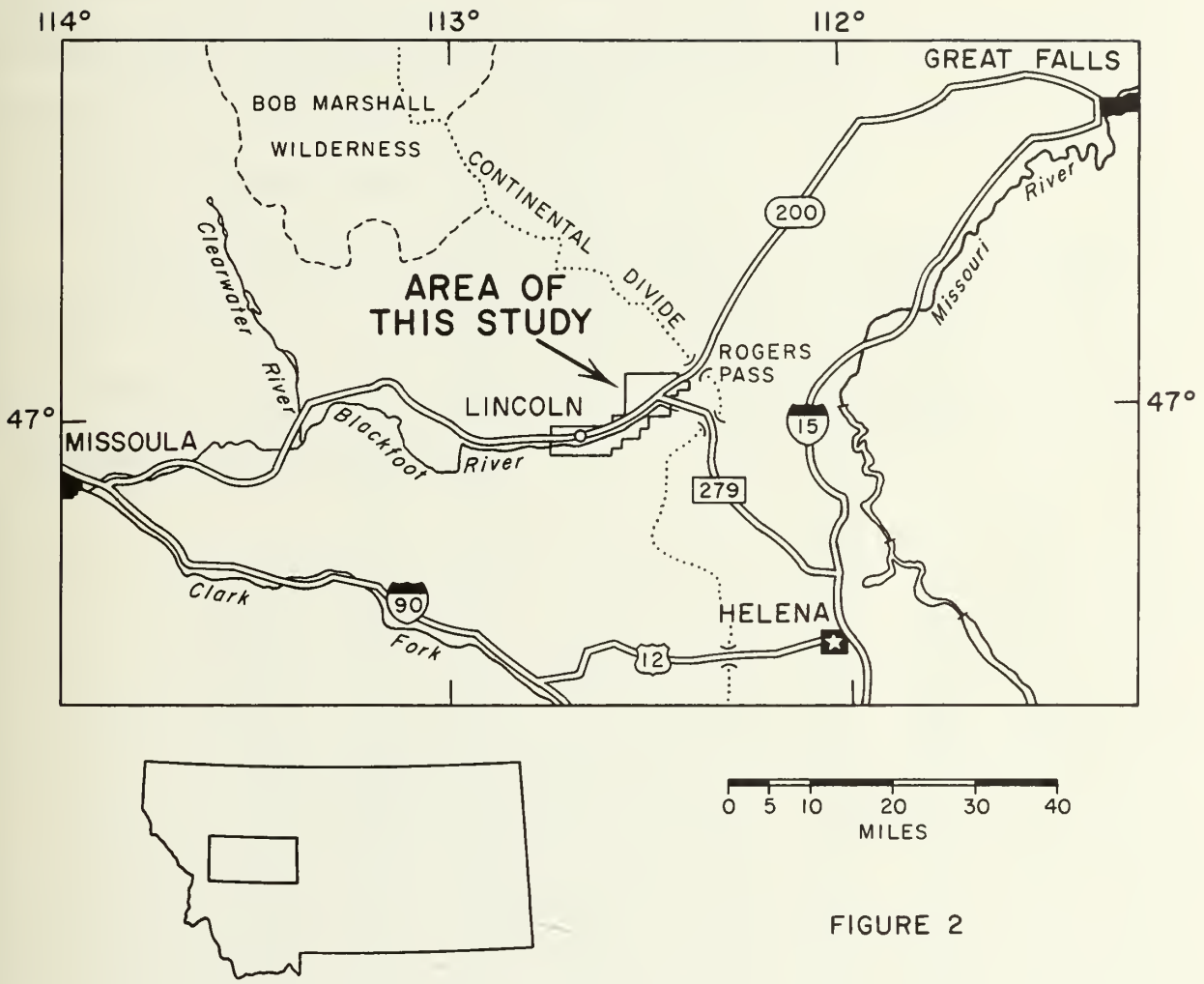


FIGURE 2

Figure 2 -- Study area, principal towns, and drainage.

are perennial. Cadotte Creek is perennial to about a mile upstream from its mouth; downstream from this point streamflow during the late summer, fall, and winter seeps into the alluvium.

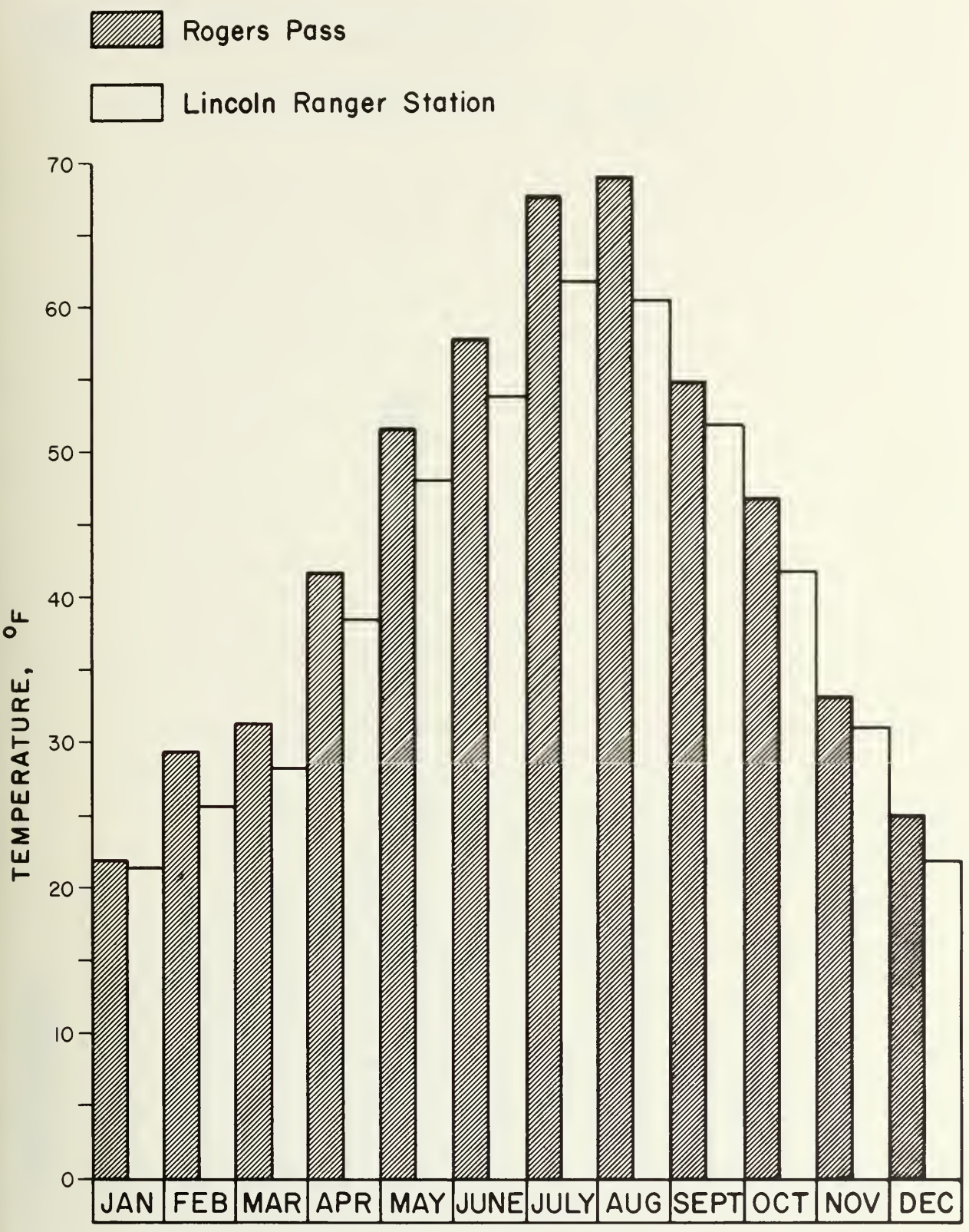
No streamflow stations have been established on the tributaries; however, miscellaneous discharge measurements (table 2) were made during this study near the mouths of Cadotte, Alice, and Willow Creeks. A streamflow and water-quality station was established in cooperation with the Montana Fish and Game Department in October 1968 on the Blackfoot River at location 15N6W19adc and was moved to location 14N7W5cdd in October 1970.

Reaches of the Blackfoot River a mile upstream from the mouth of Willow Creek and between Lincoln and the mouth of Hogum Creek are reported to go dry during the winter. Some water in the stream goes into storage as ice, the remainder seeps into the alluvium.

TEMPERATURE AND PRECIPITATION

Temperature and precipitation records have been collected by the National Weather Service at Lincoln Ranger Station, which is about a mile east of Lincoln, and at Rogers Pass, which is about a mile northeast of the eastern boundary of the study area. Based on the records from 1965-69, the average monthly temperatures are lower at Lincoln Ranger Station (figure 3) than at Rogers Pass. The difference in average monthly temperature may be caused by differences in topography and elevation between the two stations. The Rogers Pass station (elevation, 5,609 feet) is near the crest of a ridge, whereas the station at Lincoln Ranger Station (elevation, 4,575 feet) is near the center of the Blackfoot River valley and is surrounded by mountains. Temperature inversions and less wind could account for lower average temperature at Lincoln Ranger Station. The station at Rogers Pass has recorded the lowest temperature on record in the conterminous United States, -70°F on January 20, 1954.

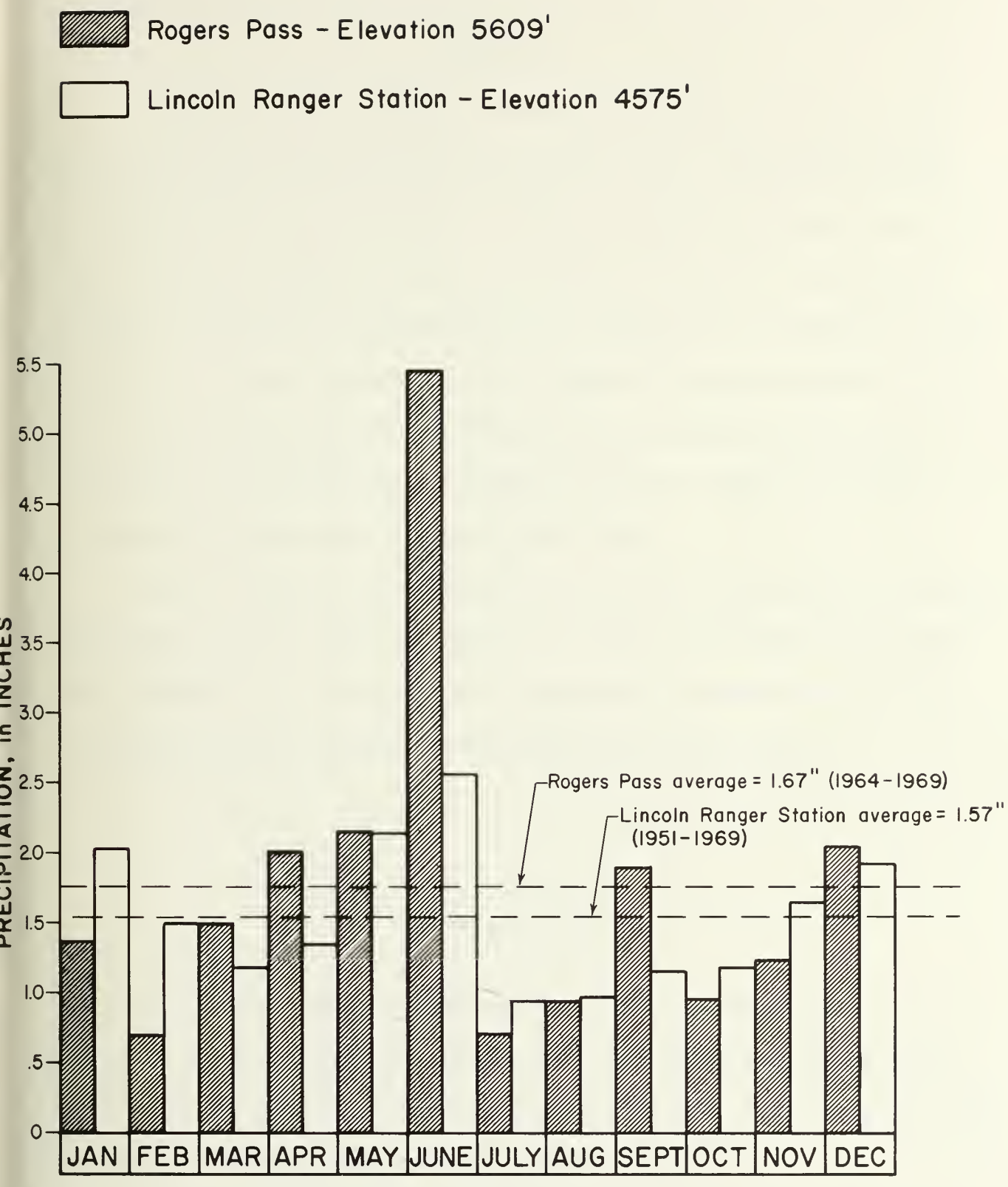
Average annual precipitation is 21.0 inches at Rogers Pass and 18.6 inches at Lincoln Ranger Station (figure 4). Greater precipitation at Rogers Pass is probably due to its higher elevation. The average of the average annual precipitation at the two stations is nearly 20 inches, which is considered to be the average precipitation over the study area. Average precipitation from October through March totals 7.8 inches at Rogers Pass and 9.4 inches at Lincoln Ranger Station. During this period precipitation is usually snow.



Mean monthly temperature

1965-1969

Figure 3 -- Mean-monthly temperature at Lincoln Ranger Station, and Rogers Pass, Montana, 1965-69.



Mean monthly precipitation

Figure 4 -- Mean-monthly precipitation at Lincoln Ranger Station, 1951-69, and Rogers Pass, Montana 1964-69.

GEOLOGY

The occurrence and distribution of the most important water-bearing rocks in the study area are discussed in this section of the report. The geologic setting is described and the glacial and glacial-related events that have produced the most important water-bearing rocks are emphasized. The aquifer characteristics and the interrelation of the geohydrologic units are determined by geologic processes; therefore, knowledge of geology is helpful in understanding the groundwater system. In the second part of the section the lithology and hydrology of the units shown on figures 5 and 6 are discussed. The appendix contains a glossary, in which are defined the geohydrologic terms used in this report.

The units shown on figures 5 and 6 represent rocks having similar geohydrologic properties, but may not represent rocks of similar ages. For example, the basement rocks include rocks of Precambrian and Tertiary ages. On the other hand, parts of the units labeled alluvium, till, and outwash are equivalent in age.

GEOLOGIC SETTING

Rocks of the Precambrian Belt Supergroup are the framework that underlies the younger rocks most important to this study. The Precambrian rocks have been intruded, folded, faulted, and have been covered in places by extrusive igneous rocks or by unconsolidated or semiconsolidated sediments.

The regional fault system trends north and west. Movement along the major faults and along minor east-west trending faults produced depressions that became

partly filled by volcanic material and by material eroded from the Precambrian rocks. The maximum thickness of fill is unknown; however, test holes 14N7W5cdd2 and 15N7W21cbb penetrated 120 feet and 144 feet respectively of semiconsolidated fill without reaching the base. This fill probably is of Tertiary age and probably has been faulted. Sections D-D' and E-E', figure 6, show that the Tertiary (?) fill rests on Precambrian rocks and underlies the unconsolidated alluvium or till.

Overlying the Tertiary (?) fill and Precambrian rocks are unconsolidated glacial-related rocks and alluvium. Glacial ice invaded the area from the north at least twice. The first invasion, which was the most extensive, deposited terminal moraines and outwash 2 miles south and west of Lincoln. During this first advance, ice moved down the broad valley north of Lincoln and down the Landers Fork and Alice Creek valleys to the Blackfoot valley. Ice from the Landers Fork-Alice Creek area probably moved southwest down the Blackfoot valley and joined the ice moving down the broad valley north of Lincoln. No till was observed in the Blackfoot valley between the mouth of Landers Fork and 2 miles east of Lincoln; however, till deposited by the first advance is almost 700 feet above the valley floor at 15N7W31db Because the ice was at least 700 feet thick near the mouth of Landers Fork, it seems likely that ice continued on down the Blackfoot valley to Lincoln.

Till and outwash deposited by the first advance is best exposed south of the Blackfoot River near Lincoln and about a mile northwest of Lincoln. Caliche is relatively abundant and many cobbles are so deeply weathered that they crumble at a touch. These deposits are generally yellowish brown.

Although the second advance was less extensive than the first, deposits related to the second are much better exposed. Cobbles and boulders are relatively unweathered and caliche is present only in small quantities. Till and outwash

GEOLOGY MAP

EXPLANATION

Pleistocene and Holocene — QUATERNARY

Qal
Alluvium
Along the Blackfoot River a mixture of sand, gravel, and cobbles cantaining beds of silt and clay. A mixture of clay, silt, sand, gravel and cobbles alang the tributories. Alluvium along the Blackfoot River has the highest permeabilty of all geohydrologic units.

Ql
Lakebed deposits
Silt and clay depasited in a lake formed when glacial ice blocked the Blackfaot valley; almost impermeable.

Qo
Outwash
Heterogeneous mixture of clay, silt, sand, gravel, and boulders; contains slightly less clay than till contains; low permeability

Qt
Till
Heterogeneous mixture of clay, silt, sand, gravel, and boulders; cantains 50 percent or more clay and silt; almost impermeable

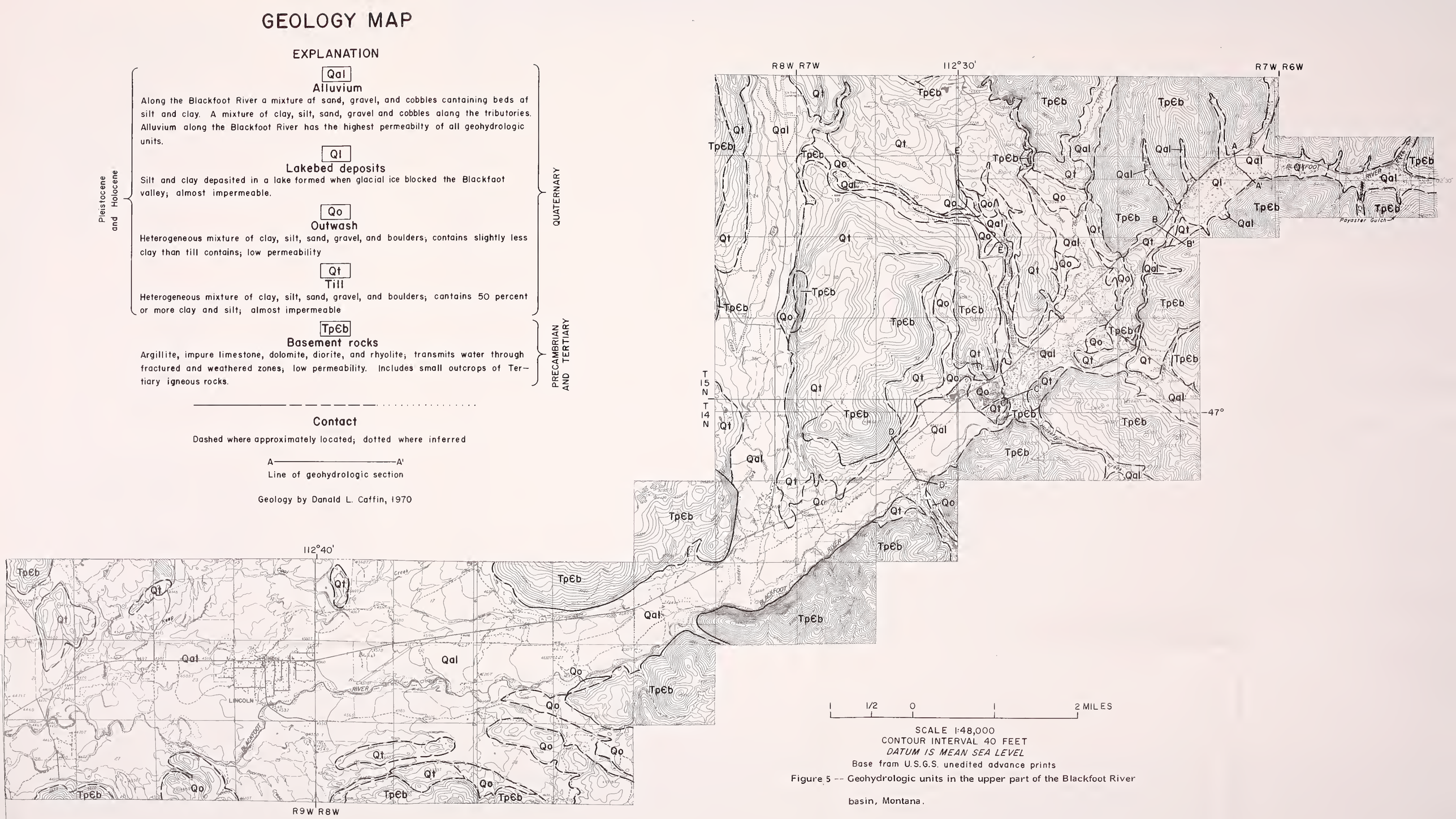
PRECAMBRIAN AND TERTIARY

TpЄb
Basement rocks
Argillite, impure limestone, dolomite, diorite, and rhyolite; transmits water through fractured and weathered zones; low permeability. Includes small outcrops of Tertiary igneous rocks.

Contact
Dashed where approximately located; dotted where inferred

A——————A'
Line of geohydrologic section

Geology by Danald L. Caffin, 1970



1/2 0 2 MILES

SCALE 1:48,000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S.G.S. unedited advance prints

Figure 5 -- Geohydrologic units in the upper part of the Blackfoot River basin, Montana.

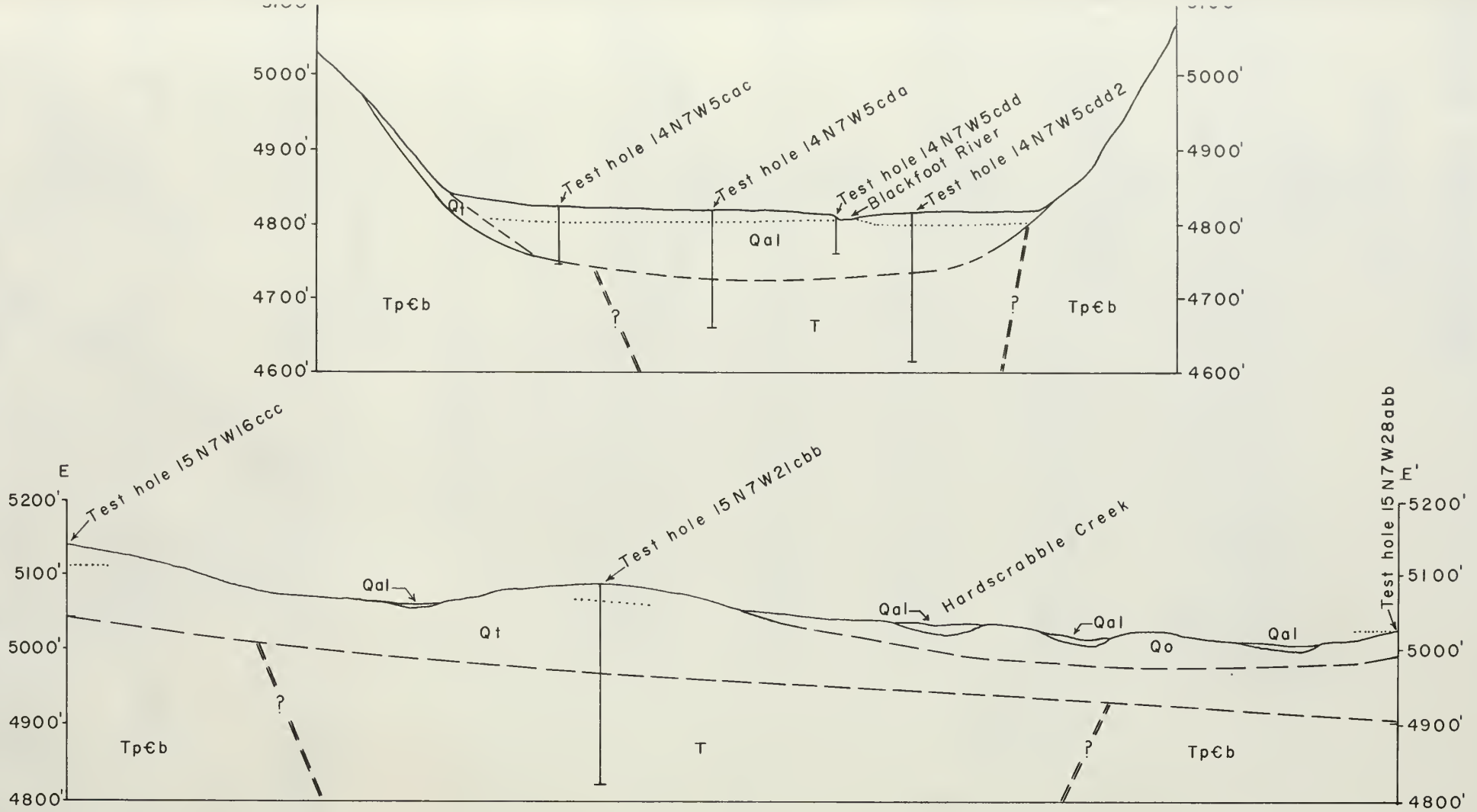


Figure 6 -- Geohydrologic cross sections.

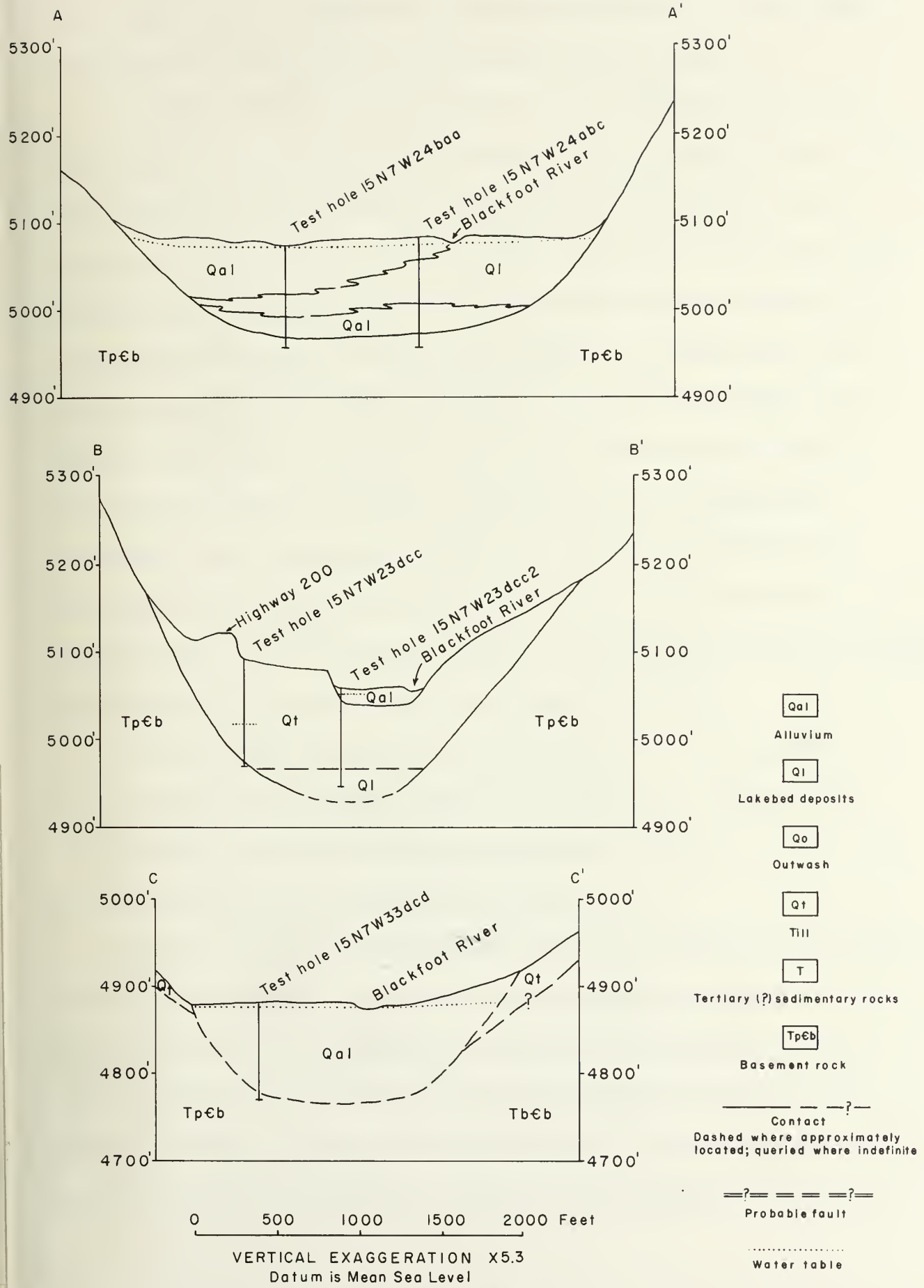


Figure 6 -- Geohydrologic cross sections.

from the second ice mass are generally light red or pinkish red. The approximate maximum extent of ice during the second advance is shown in figure 6a.

In the study area, the principal tongue of ice moved down the Landers Fork valley during the second advance. Ice overflowed the east side of the valley (15N7W18), flowed southeastward, and blocked the Alice Creek valley forcing Alice Creek to cut a canyon in rock on the east side of its valley. The ice turned south and blocked the Bartlett Creek valley. Ice covered the Hardscrabble Creek basin and deposited till over most of the basin. The ice continued southward to the Blackfoot valley, blocked the upper Blackfoot valley, and formed a lateral moraine (15N7W23 and 15N7W26). A lake that formed behind the ice and the lateral moraine was partly filled by glaciolacustrine clay and silt. The ice continued to the south side of the Blackfoot valley and deposited a terminal moraine that now partly blocks the Willow Creek valley. This terminal moraine also partly blocks the Blackfoot valley at Flesher Lakes. The ice and moraines caused the Blackfoot River to cut new channels into Precambrian and igneous rocks on the south side of the valley.

Ice in the Landers Fork valley extended to the mouth of the valley where a terminal moraine was deposited. Except in the Landers Fork, Hardscrabble, and Alice Creek valleys, and a short reach of the Blackfoot River valley, the study area was apparently free of ice during the second advance.

Melt water from the ice reworked some of the till and redeposited it as outwash. The outwash shown on figure 5 is poorly sorted and contains only a slightly smaller amount of clay than does till. Material that has been more thoroughly reworked and transported relatively long distances is shown on figure 5 as alluvium. On the east side of the Landers Fork valley near its mouth, till in the moraine grades southward into poorly sorted outwash, which in turn grades southward and

eastward into moderately well sorted alluvium.

GEOLOGIC AND HYDROLOGIC CHARACTERISTICS

Basement Rocks

Basement rocks include sedimentary rocks of the Belt Supergroup of Precambrian age, intrusive igneous rocks of Precambrian and Tertiary(?) ages, and extrusive igneous rocks of Tertiary(?) age. Rocks of the Belt Supergroup include the Spokane and Empire Formations and the Helena Dolomite. Younger Precambrian sedimentary rocks are exposed north of the study area. The Spokane and Empire Formations consist of thin beds of argillite and siltite, generally maroon or greenish-gray. The Helena Dolomite overlies the Empire Formation and consists of relatively thick beds of silty or clayey dolomite and limestone, separated by thin beds of argillite. The Helena Dolomite is dark gray and weathers brownish gray. Total thickness of the Spokane and Empire Formations and the Helena Dolomite is more than 5,000 feet.

Rocks of the Belt Supergroup contain water in fractures. No wells are known to yield water from these rocks in the study area, probably because water is easier to obtain from other sources. Precambrian sedimentary rocks in other areas yield as much as 0.02 cfs (cubic foot per second) to wells and the rocks would likely yield similar quantities in the study area. In most places the rocks are not highly fractured and are nearly impermeable in comparison to the alluvium. The area underlain by Precambrian sedimentary rocks is large, however, and the yield from the area sustains the flow of streams. The sediments could yield enough water

to a large excavation to cause engineering problems. For example, if an excavation approximates a cylinder that is 2,000 feet in diameter and 1,000 feet deep and that penetrates saturated rocks having a transmissivity of 130 square feet per day and storage coefficient of 0.01, the 1-2 cfs would have to be pumped to keep the excavation dry. The example assumes values for transmissivity and storage coefficient that are in the range to be expected in Precambrian sedimentary rocks and also assumes that flow to the excavation can be predicted by a mathematical model describing nonsteady flow to a well of constant drawdown (Ferris and others, 1962, p. 106).

The major intrusive into the Precambrian sedimentary rocks is a diorite sill of Precambrian age. Pardee and Schrader (1933, p. 89) report the sill is about 500 feet thick and composed principally of hornblende and feldspar, but is more basic in composition at some places. Test hole 15N7W28abb encountered diorite at 123 feet and penetrated 7 feet before drilling was stopped. The upper 5 feet is weathered and highly fractured and the lower 2 feet is little weathered but probably fractured. Pebble-sized pieces of diorite recovered from the bottom of the hole are gray and composed of hornblende phenochrysts in a feldspathic groundmass. Pardee and Schrader (1933, pl. 2) show that the diorite crops out on each side of the Blackfoot River upstream from Alice Creek. In the study area no other exposures were observed or reported, but diorite was penetrated by test holes in the Blackfoot River valley upstream from Flesher Lakes and in the Hardscrabble Creek drainage (table 7).

The diorite transmits water through fractures and weathered zones. A 5-hour pumping test (table 1) of test hole 15N7W28abb indicates that the transmissivity of the 7-foot interval of diorite and weathered diorite is 890 square feet per day. Data were insufficient to calculate the storage coefficient; however, because the

water in the diorite at the test site is under artesian pressure, its storage coefficient is probably in the range of 10^{-4} to 10^{-5}. Although the diorite seemingly is capable of transmitting more water than the Precambrian sedimentary rocks, it is not considered to be an important aquifer because of its relatively small areal extent. In most places where the diorite is saturated it is overlain by more permeable alluvium or by relatively impermeable till or outwash. Excavations or mines penetrating diorite would require drainage facilities to keep them dry during all seasons.

Small dikes and sills of Late Cretaceous or Tertiary age intrude the Precambrian rocks near the mouth of Pass Creek and other places outside the study area. The extent of these rocks is relatively small and their hydrologic characteristics are believed to be similar to the Precambrian rocks.

Extrusive igneous rocks of Tertiary(?) age crop out on the south side of the Blackfoot River south of Flesher Lakes and along the east side of the Landers Fork valley. Structural, lithologic, and stratigraphic relations are not clear because of poor exposures and difficult accessibility.

Along the east side of the Landers Fork, at 15N8W36aa, a welded tuff sequence is overlain by a crudely stratified deposit of rhyolite porphyry cobbles and light-gray sandy silt. Both the welded tuff sequence and the stratified deposit dip 10^{o} to 15^{o} to the northeast. The lowest bed exposed in the welded tuff sequence is a glassy perlite, which is overlain by rhyolite porphyry. The crudely stratified deposit appears to have been deposited by water.

The extrusive igneous rocks occupy topographically high positions and are of relatively small areal extent. They are mostly drained and seem to be of little importance in the hydrologic system of the upper Blackfoot drainage.

Tertiary(?) Sedimentary Rocks

Sedimentary rocks similar in appearance to rocks of Tertiary age in other areas in western Montana were penetrated by test holes 14N7W5cdd2, 14N7W5cda, and 15N7W21cbb (figure 6 and table 7). None of these test holes reached the base of the Tertiary(?) rocks. Rocks like those found in the test holes are not exposed in the study area but crop out at 15N9W29cda. Two test holes (14N7W5cdd2 and 14N7W5cda) penetrated, beneath the alluvium, 114 and 55 feet of semiconsolidated light-gray clay containing interbedded conglomerate, sandstone, and limestone. Immediately beneath the alluvium is 10 to 16 feet of light-yellow-brown clay and gravel, which may be a weathered zone of the light-gray rocks. The light-gray rocks seem to be in layers less than a foot thick; however, percussion drilling methods make it difficult to be certain exactly how thick these beds are. The light-gray clay is sandy and contains organic material as well as tiny, well-formed crystals of pyrite and grains of magnetite. The sandstone is medium to very coarse grained, being composed mostly of quartz and shards of volcanic glass with abundant crystals of pyrite and grains of magnetite. The conglomerate is composed of well-rounded pebbles of argillite and a fine-grained black unidentified rock. The conglomerate contains small light-green chert pebbles. The conglomerate is noncalcareous and poorly cemented. The limestone is light pinkish brown and contains silt and pyrite.

Test hole 15N7W21cbb penetrated 119 feet of glacial till overlying 144 feet of clay that contains thin beds of sand and gravel. The lower 144 feet is predominantly unconsolidated sandy clay that ranges in color from bluish gray to reddish brown or lavender. The sand is composed mostly of quartz and volcanic glass, but grains of argillite and of a black unidentified rock are common. Gravel-sized particles

are mostly argillite, limestone, and the black rock.

The sediments penetrated by test hole 15N7W21cbb have a wider range in color and a greater clay content, are less compacted, and contain fewer grains of pyrite and magnetite than the sediments penetrated by test holes 14N7W5cdd2 and 14N7W5cda. These differences may indicate an age difference or a different environment of deposition. Considerably more data would be necessary to determine the geologic relations between the deposits. Geologic consideration and test drilling indicate that Tertiary(?) sedimentary rocks underlie the alluvium along the Blackfoot valley from 3 miles west of Lincoln to and including part of the Hardscrabble Creek drainage area.

Tertiary(?) sedimentary rocks penetrated by test holes, 14N7W5cdd2 and 14N7W5cda transmit water through the thin beds of sandstone and conglomerate and perhaps through fractures in the sandy clay. The transmissivity of these sediments was estimated from a bailing test of test hole 14N7W5cdd2. At the completion of drilling, this hole was cased to 160 feet with nonperforated casing. The lower 40 feet of the hole was uncased. The hole was developed by bailing and light surging for 5 hours and after waiting 12 hours was bailed at an average rate of 0.11 cfs for 2 hours. At the end of bailing, the water level had been drawn down 11.2 feet and after 6 minutes had recovered to the pre-bailing level of 15.8 feet below land surface. The specific capacity of the test hole after 2 hours of bailing was 0.59 square foot per minute. The specific capacity indicates the transmissivity to be about 1,300 square feet per day.

A similar bailing test of test hole 14N7W5cda was unsuccessful because the casing had 5 feet of perforations opposite the alluvium. The alluvium has a much higher transmissivity than the Tertiary(?) sedimentary rocks, and the bailing

rate was too small to cause any measurable drawdown in the well when water was supplied by both the alluvium and Tertiary(?) sedimentary rocks.

Tertiary(?) sedimentary rocks penetrated by test hole 15N7W21cbb yielded only small quantities of water during drilling and when the hole was bailed dry it required more than 12 hours to refill.

The bailing tests indicate a range in transmissivity of the Tertiary(?) sedimentary rocks from nearly zero in the Hardscrabble Creek drainage to roughly 1,300 square feet per day in the Blackfoot River valley. Water in these sediments in the Blackfoot valley is under artesian pressure; thus the storage coefficient is probably in the range 10^{-3} to 10^{-5}. A well in the Blackfoot valley completed in Tertiary(?) sedimentary rocks similar to those at test hole 14N7W5cdd2 would have an initial yield of about 0.5 cfs with a drawdown of 50 feet if the storage coefficient is 10^{-4}.

Till

Till is a mixture of clay, silt, sand, gravel, and boulders that has been deposited by glacial ice. In general, clay- and silt-sized particles compose more than half the till, but the percentage composition depends partly on its distance from the source. Till derived from nearby basement rocks contains 60 to 70 percent pebbles, cobbles, and boulders. Till carried a relatively long distance has had most of the large rocks reduced to clay- and silt-sized particles. In the study area till is unsorted, but sand and gravel lenses or beds less than 10 feet thick are found in some places. Dominant rock types of boulders and cobbles are argillite,

quartzite, limestone, and dolomite. The till is light red to pink.

Till has been plastered along the sides of the south-flowing tributary valleys between Bartlett Creek and Landers Fork and forms moraines that partly block the mouths of some valleys. The most evident moraine is the one blocking the Blackfoot River and Willow Creek valleys. The sides of the moraines are steep; however, artificial cuts in till slump when saturated by water.

The maximum or average thickness of the till is unknown. Two test holes (15N7W23dcc and 15N7W23dcc2) drilled through the moraine in the Blackfoot valley penetrated 121 and 72 feet of till. Thicker sections of till would have been penetrated half a mile west of the test holes because the moraine is higher. Test holes 15N7W16ccc, 15N7W21cbb, and 15N7W28abb penetrated 93, 119, and 88 feet of till. Till plastered on the valley walls is probably less than 20 feet thick.

The high percentage of clay-sized particles in the till makes it nearly impermeable. The till has the lowest permeability of the geohydrologic units in the study area. In most areas in the valleys the till is saturated; however, pore spaces in the till are tiny and do not allow water to drain from them. Beds of sandy or gravelly till, however, contain larger pore spaces, and these beds yield water to wells and springs. The sandy beds are thin and lenticular; therefore, the yield to wells and springs is small. Till generally impedes the movement of water into underlying strata and allows water to accumulate in the overlying or adjacent deposits, or confines water in the underlying deposits under artesian pressure.

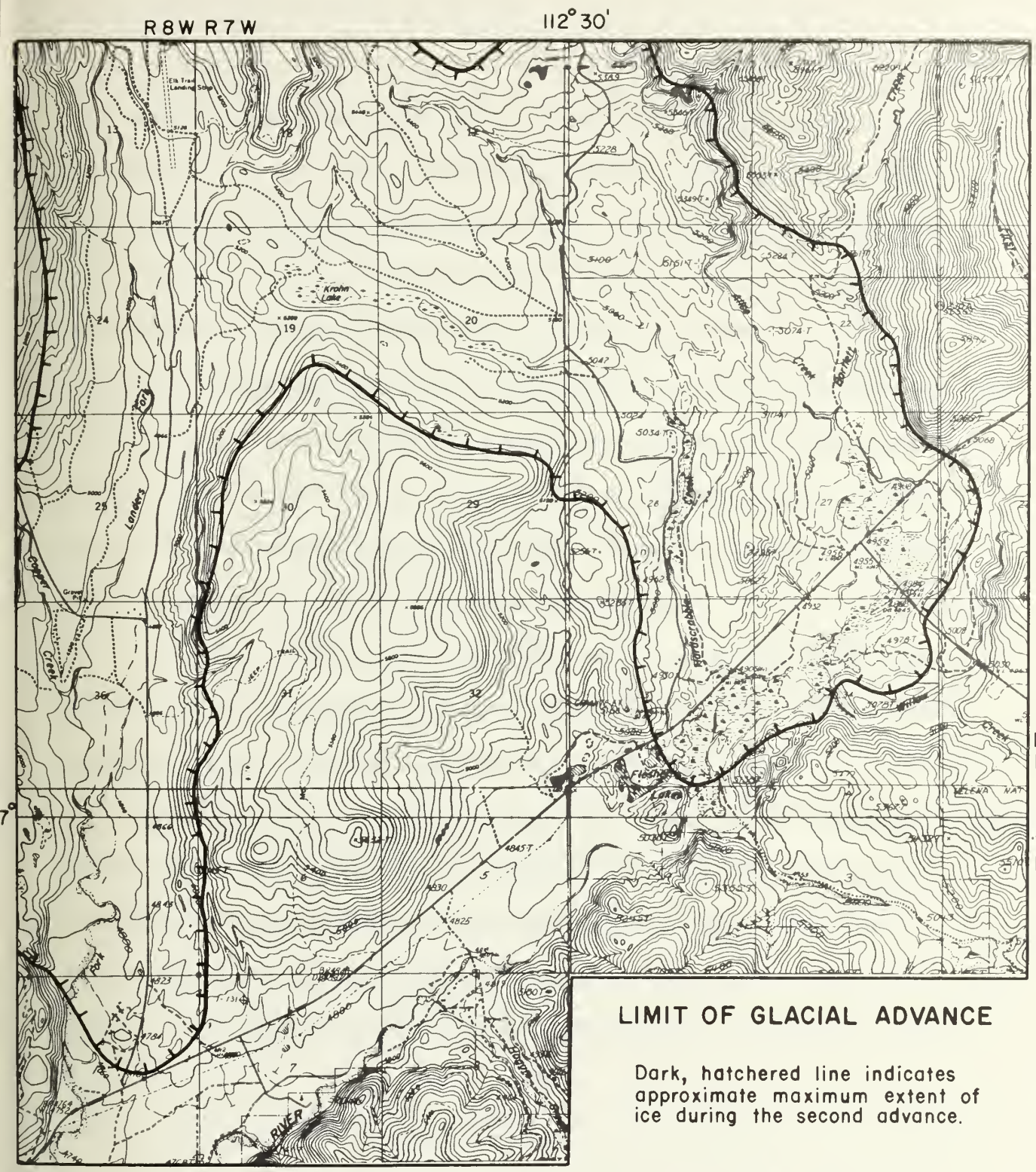

R8W R7W
112°30'
T 15 N
T 14 N
LIMIT OF GLACIAL ADVANCE
Dark, hatchered line indicates approximate maximum extent of ice during the second advance.
Base from U.S.G.S. unedited advance prints
SCALE 1:48,000
1 ½ 0 1 2 MI.
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

Figure 6a -- Maximum extent of ice during the second advance.

Outwash

Outwash is almost as heterogeneous a mixture of clay, silt, sand, gravel, and boulders as the till. Slight reworking of the till by meltwater has removed some of the clay and fine-grained material, but except for about 10 percent less clay, outwash is as poorly sorted as the till. The outwash shown on figure 5 has been transported only short distances and is difficult to differentiate from till in the outcrop. The principal rock types of the gravel are argillite, quartzite, limestone, and dolomite. The grains range from subangular to rounded, the largest grains being the more rounded. Because of the large amount of light-red and pink clay, the outwash is light-red to pink. Outwash forms smoother and flatter slopes than till. Outwash grades laterally into till and into alluvium.

Test holes 15N7W28abb and 15N7W28dcb (table 7) penetrated 35 feet and 80 feet of outwash respectively. However, not enough test holes have been drilled through the outwash to determine average or maximum thickness.

The outwash contains nearly as much clay as the till and is almost as impermeable. Outwash did not yield water to the test holes and it was necessary to add water for drilling. Although no beds in the outwash were observed to yield water to wells or springs, beds capable of transmitting small quantities of water may be present. The principal hydrologic functions of the outwash are the same as for till.

Lakebed Deposits

Silt and clay accumulated in a lake that formed when the ice flowing down the Hardscrabble-Alice Creek valley blocked the Blackfoot River. The lake covered about 1 square mile at its maximum extent. Tributaries flowing into the lake from the north deposited sand and gravel that interfingers into silt and clay, which accumulated in quiet water in the lake (figure 6, line A-A'). The silt and clay ranges in thickness from nearly zero where it interfingers with the alluvium to more than the 30 feet penetrated by test hole 15N7W24abc. The silt and clay form a thinly bedded (varved) deposit, generally light-brown or light-pinkish-gray.

The lakebed deposits are fine grained and nearly impermeable. They do not yield water to wells and confine the water in underlying deposits.

Alluvium

Alluvium derived by erosion of outwash and till has been sorted, and much of the clay- and silt-sized particles have been transported away by streams. In general, alluvium along the Blackfoot River is moderately well sorted; however, alluvium along the smaller streams such as Hardscrabble Creek is poorly sorted and retains the characteristics of its parent outwash.

Alluvium along the Blackfoot River is a mixture of subrounded to well-rounded fragments that range from clay to very coarse gravel and cobbles. The alluvium is in roughly horizontal beds that range from 3 inches to 30 feet

in thickness. All the beds are composed principally of rounded to well-rounded sand and gravel; however, some thin beds contain about 30 to 40 percent clay and silt and 10 to 20 percent very fine sand. Clay-sized material is a small percentage of the total volume of the alluvium. Very coarse gravel and cobbles are scattered throughout the alluvium but tend to be concentrated in beds 2 to 3 feet thick. Well-sorted beds of coarse sand to medium gravel average about a foot in thickness. Beds more than 3 feet thick are generally poorly sorted and range from silt to very coarse gravel.

The thickness of the alluvium along the Blackfoot River as determined by test drilling ranges from a few feet near the edges to as much as 112 feet. The average thickness is probably from 90 to 100 feet.

The principal rock fragments in the alluvium are argillite, dolomitic limestone, quartzite, and igneous rocks. In some places diorite and fine-grained igneous rocks account for more than 50 percent of the rock material. The alluvium is light red to pink due to the abundance of red or pink argillite and quartzite.

Terraces along the Blackfoot River valley are 6 to 15 feet above river level. A thin brownish sandy soil underlain by about a foot of caliche-coated sand and gravel has developed on the alluvium beneath the terraces. The alluvium forms steep terrace scarps; vertical cuts soon weather to steep slopes. Alluvium underlying the flood plain of the Blackfoot River contains a high percentage of boulders and cobbles to depths of 15-20 feet.

The alluvium along the smaller tributary streams is derived from outwash and till that has been transported only short distances or from weathered material washed from the hillsides. It is poorly sorted and contains a higher percentage of clay than the alluvium along the Blackfoot River and Landers Fork. As

shown in the log of test hole 15N7W28dcb (table 7) the alluvium along Hardscrabble Creek consists of 64 feet of very fine- to very coarse-grained sand that contains clay, silt, and fine gravel. Interbedded with the sand, clay, and silt are two thin (2 to 3 feet thick) beds of sand or sand and gravel that contain little or no clay. Underlying the alluvium is a bed of well-sorted sand and gravel that probably is related to either the first glacial advance or deposition during the Tertiary Period.

The hydrologic characteristics of the alluvium along the Blackfoot River were tested at nine sites (tables 1 and 8) by The Anaconda Company and by the U. S. Geological Survey. The tests consisted of pumping a test hole and measuring the discharge and drawdown for several hours. Steel casing in the test holes was first perforated and the test holes subsequently developed by surging and bailing until they produced sand-free water. Average pumping rates ranged from 0.18 cfs to 0.33 cfs. Pumping rates were small and the drawdown is affected by entrance losses and by incomplete development of the test holes. The results of the pumping tests, therefore, represent only approximations of the ability of the alluvium to transmit water.

Test holes 14N7W5cac and 14N7W5cda penetrated material that is apparently typical of the alluvium downstream from Flesher Lakes. The transmissivity as determined at these two sites averages 46,000 square feet per day. A pump test (table 8) of test hole 14N7W5cdd2 indicates a transmissivity about twice that of the other two test holes; however, the data are inconclusive. Because the alluvium thins near the valley walls, the transmissivity of the alluvium generally decreases along the edge of the valley.

A concept of the amount of water the alluvium is capable of transmitting

Table 1. -- Summary of pump test data

Location	Owner	Depth of test hole (feet)	Depth to water below land surface (feet)	Length of perforated casing (feet)	Length of test (minutes)	Average Pumping Rate (gpm)	Average Pumping Rate (cfs)	Drawdown at end of test (feet)	Specific capacity at the end of 100 minutes ($minutes^{-1}$)	Transmissivity ($feet^2\ day^{-1}$)	Date of Test	Aquifer	Test Hole
14N7W5cac	USGS	76	27.75	10	1,350	90	0.20	1.95	6.7	45,000	10/16-17/70	Qal	A-1
5cda	-do-	176	23.66	35	1,130	92	.20	.94	14	47,000	10/15-16/70	Qal	A-2
5cdd2	-do-	200	19.20	40	1,245	90	.20	2.10	5.7	------	10/14-15/70	Qal	A-4
15N6W20cba	TAC	65	3.28	27	100	80	.18	9.76	1.1	------	6-20-70	Qal	WO-2
20daa	-do-	53	4.78	11	365	150	.33	15.50	1.5	------	6-17-70	Qal	WO-1
21cba	-do-	76	.25	30	240	145	.32	36.14	.55	------	6-16-70	Qal	WO-3
24abc	-do-	126	5.94	40	120	120	.27	6.07	2.7	------	6-24-70	Qal	WO-1
24baa	-do-	118	2.05	46	120	150	.33	2.32	8.6	------	6-21-70	Qal	WO-4
33dcd	-do-	108	4.02	63	300	140	.31	5.54	3.3	------	6-22-70	Qal	WB-2
15N7W28abb	USGS	130	7.10	7	300	93	.21	12.13	1.2	890	10-17-70	TpEb	B-3

can be obtained from the value of transmissivity. For example, a vertical prism of alluvium 1 foot square extending the full saturated thickness will transmit 46,000 cubic feet of water per day if the hydraulic gradient is 1 to 1. This rate is equal to about 0.5 cfs of about 1 acre-foot per day. Under existing conditions the rate of transmission of water is less because the gradient is less; actual rates are discussed in the section on groundwater movement.

The average transmissivity of the alluvium along the Blackfoot River is not well known because pumping-test results are subject to different interpretations. However, the average transmissivity of the alluvium probably is greater downstream from Flesher Lakes than it is upstream. The average transmissivity is likely to be lower upstream from the lakes because the alluvium has been transported shorter distances and in general is not as well sorted. Also, fine-grained material would tend to be deposited on the upstream side of the moraines, which partly block the valley upstream from Flesher Lakes.

The average transmissivity of the alluvium upstream from Flesher Lakes can be estimated from the transmissivities obtained from test holes 14N7W5cac and 14N7W5cda and from the specific capacities. The specific capacity of a well varies slowly with the time of discharge, but if it is constant except for the time variation, it is proportional to the transmissivity of the aquifer (Lohman and others, 1970, p. 32). Well construction and development practices may affect the specific capacity; therefore, estimates of aquifer transmissivity based on specific capacity can be considerably in error. The average specific capacity determined from pumping tests of test holes 14N7W5cac and 14N7W5cda is 8.8 square feet per minute and the average transmissivity is at least 46,000 square feet per day. Upstream from Flesher Lakes the average specific capacity of test holes that penetrate alluvium is 3.0

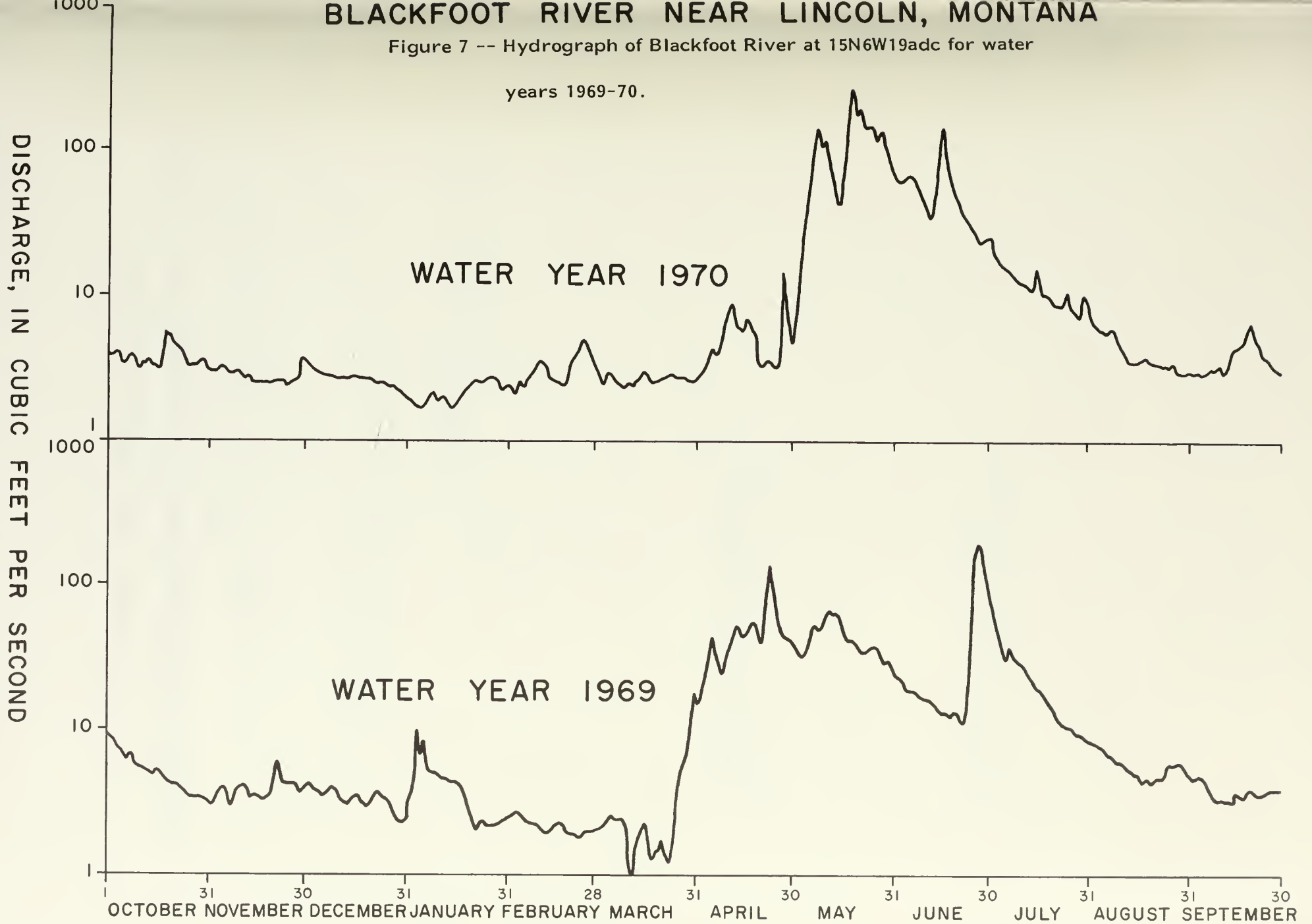
square feet per minute. If the specific capacity values are proportional to the transmissivity, then the average transmissivity of the alluvium upstream from the lakes is about 15,000 square feet per day. Variations from the average should be expected because of local differences in lithology and saturated thickness.

Transmissivity is usually considered a measure of the aquifer's ability to transmit water in a horizontal direction. Water also moves vertically from streams into and out of the aquifer. The ability of an aquifer to transmit water vertically is usually much less than its ability to transmit water horizontally. No measures of the vertical permeability of the alluvium along the Blackfoot River have been made, but the ratio of the vertical to horizontal permeability is probably less than 1 to 10.

The specific yield downstream from Flesher Lakes probably averages about 0.20. Upstream from the lakes the silt and clay content of the alluvium is higher and the specific yield probably averages from 0.10 to 0.15.

BLACKFOOT RIVER NEAR LINCOLN, MONTANA

Figure 7 -- Hydrograph of Blackfoot River at 15N6W19adc for water years 1969-70.



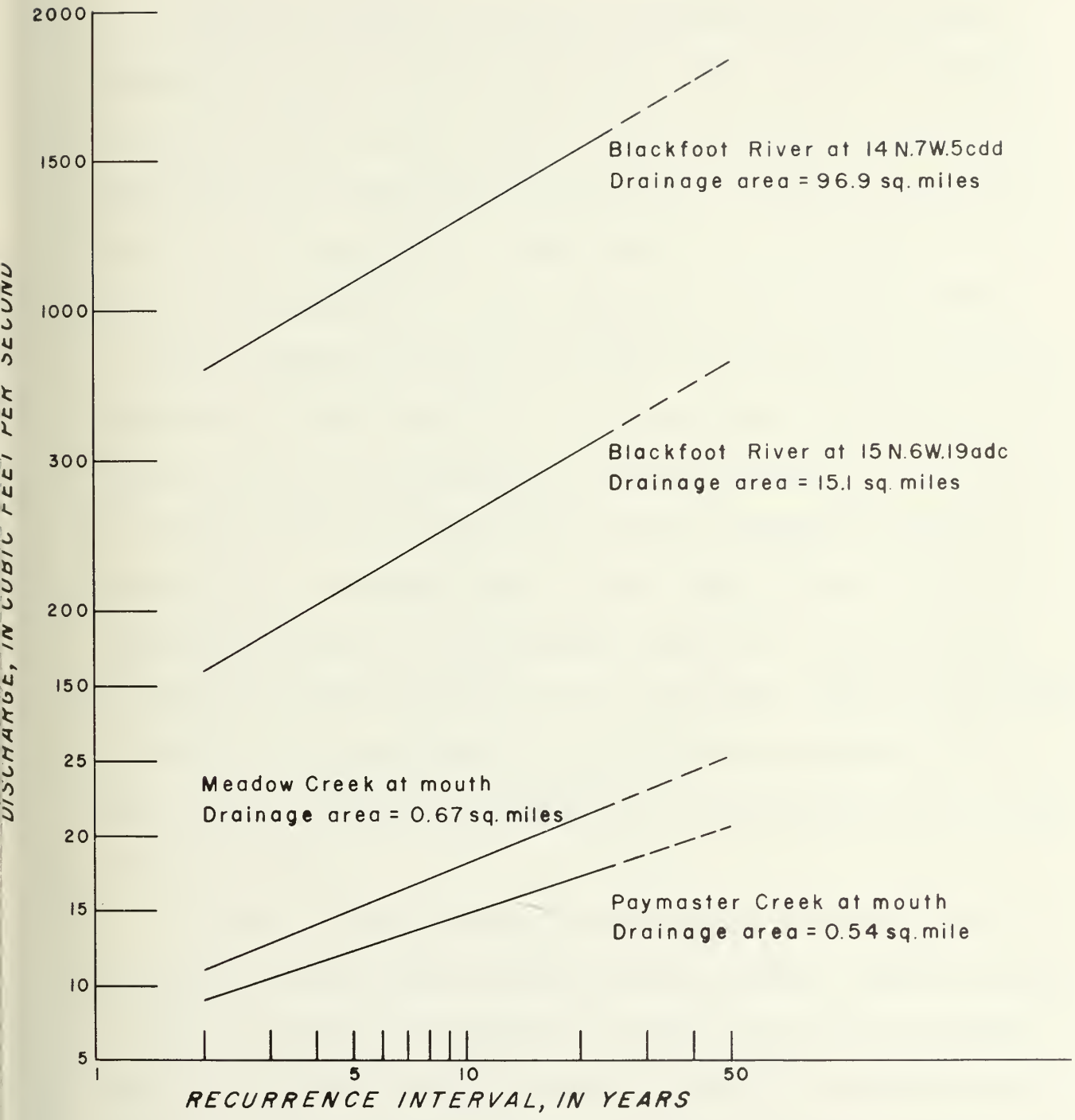


Figure 8 -- Flood-frequency curves for the Blackfoot River at15N6W19adc and 14N7W5ccd, Meadow Creek, and Paymaster Creek.

HYDROLOGY

SURFACE WATER

A streamflow station was operated on the Blackfoot River near Lincoln at 15N6W19adc from October 1968 through September 1970. The record collected at this station constitutes the major record of surface-water flow in the study area. A hydrograph of the Blackfoot River, which drains 15.1 square miles upstream from this site, is shown in figure 7. Mean monthly flows varied from 2.14 cfs in February 1969 to 103 cfs in May 1970. Streamflow increases at the end of March or in April in response to snowmelt. Flow remains high through June, with peaks being caused by rainfall runoff into the stream in addition to runoff from snowmelt. Beginning in July, streamflow generally recedes through summer, fall, and winter to a minimum in February or March. The recession is caused by a decrease in average monthly precipitation in July and August (figure 4) and by increase in evapotranspiration due to warmer temperatures (figure 3). The recession may be interrupted in September by an increase in precipitation. Most of the precipitation from October until March is stored as snow, which remains unmelted until late March or April. The flow of the Blackfoot River is sustained mostly by groundwater in the fall and winter.

Streamflow records in the study area are much too short to allow them to be extended accurately in time or space by statistical methods. However, analyses of floods, based on basin characteristics, have been made by Boner and Omang (1967) and by Bodhaine and Thomas (1964). The analyses relate flood frequency at streamflow stations having relatively long records to basin characteristics such as drainage area, average elevation, channel slope, and average annual runoff.

The characteristics can be measured for any site in a drainage area and used to estimate flood frequency. Reliability of the estimate depends on the amount of streamflow data originally used to relate flood frequency to basin characteristics.

Flood-frequency curves for four sites in the study area are shown in figure 8. The recurrence interval of a flood is the average interval of time within which the given flood during a given year is the inverse of the recurrence interval. For example, a 10-year flood has a 10 percent chance of occurring in any year, and a 25-year flood has a 4 percent chance of occurring in any year. The graphs do not imply that a given flood will always occur within a given interval or that a larger flood cannot occur. For example, the peak flow in 1964 at 14N7W5cdd was estimated by an indirect measurement to be 3,500 cfs, which is almost three times the magnitude of a 50-year flood. The curves in figure 8, though based on incomplete data, may be helpful in designing drainage or mine-waste disposal facilities.

GROUNDWATER

All hydrogeologic units shown on figure 5 contain water. The units differ considerably, however, in their ability to store and transmit water. On the average, alluvium is capable of storing and transmitting several times more water per unit volume than the other hydrogeologic units. Where silt and clay compose a high percentage of the alluvium, however, the alluvium is a poor aquifer. Areas where the alluvium at land surface is composed mostly of sand and gravel are shown on figure 9. Though highly generalized, this map shows the area where test drilling

WATER–TABLE MAP

EXPLANATION

○ 4773

Well or test hole
Number is elevation of the water table, in feet above mean sea level, during the summer of 1970

▲

Streamflow station

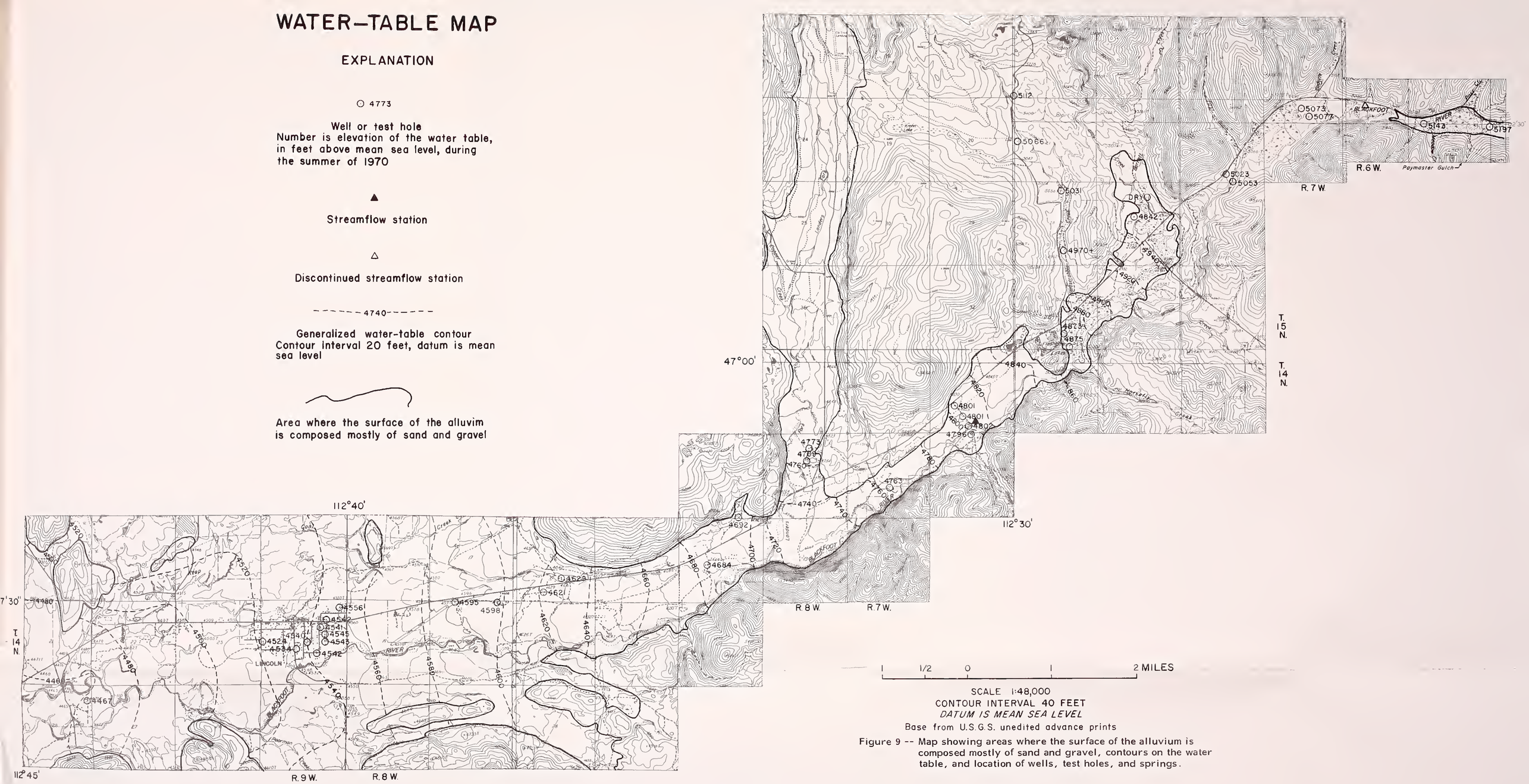
△

Discontinued streamflow station

------4740------

Generalized water-table contour
Contour interval 20 feet, datum is mean sea level

Area where the surface of the alluvim is composed mostly of sand and gravel



SCALE 1:48,000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

Base from U.S.G.S. unedited advance prints

Figure 9 -- Map showing areas where the surface of the alluvium is composed mostly of sand and gravel, contours on the water table, and location of wells, test holes, and springs.

may locate sites suitable for large-capacity wells or where test drilling may locate sites where water-soluble material could be expected to reach the water table. Some alluvium near the edges of the valleys may not be saturated; thus, the use of figure 9 in these areas requires judgment based on knowledge of local conditions. Wells can be developed in areas other than those outlined on figure 9; however, sustained yields probably will be smaller than in the outlined areas.

Recharge

All the geohydrologic units in the study area are recharged directly or indirectly by precipitation. Most precipitation runs off or is evaporated and transpired. Infiltration of precipitation is greatest from April through June when the ground becomes nearly saturated by snowmelt and rain and when evapotranspiration has not reached its peak because the average daily air temperatures are low. Infiltration may occur any time; however, infiltration rates are greatest in spring and early summer because precipitation is greatest. In midsummer moisture available for infiltration is evaporated and transpired. In late summer and fall precipitation decreases. Cold temperatures in winter cause moisture to go into storage as ice and snow.

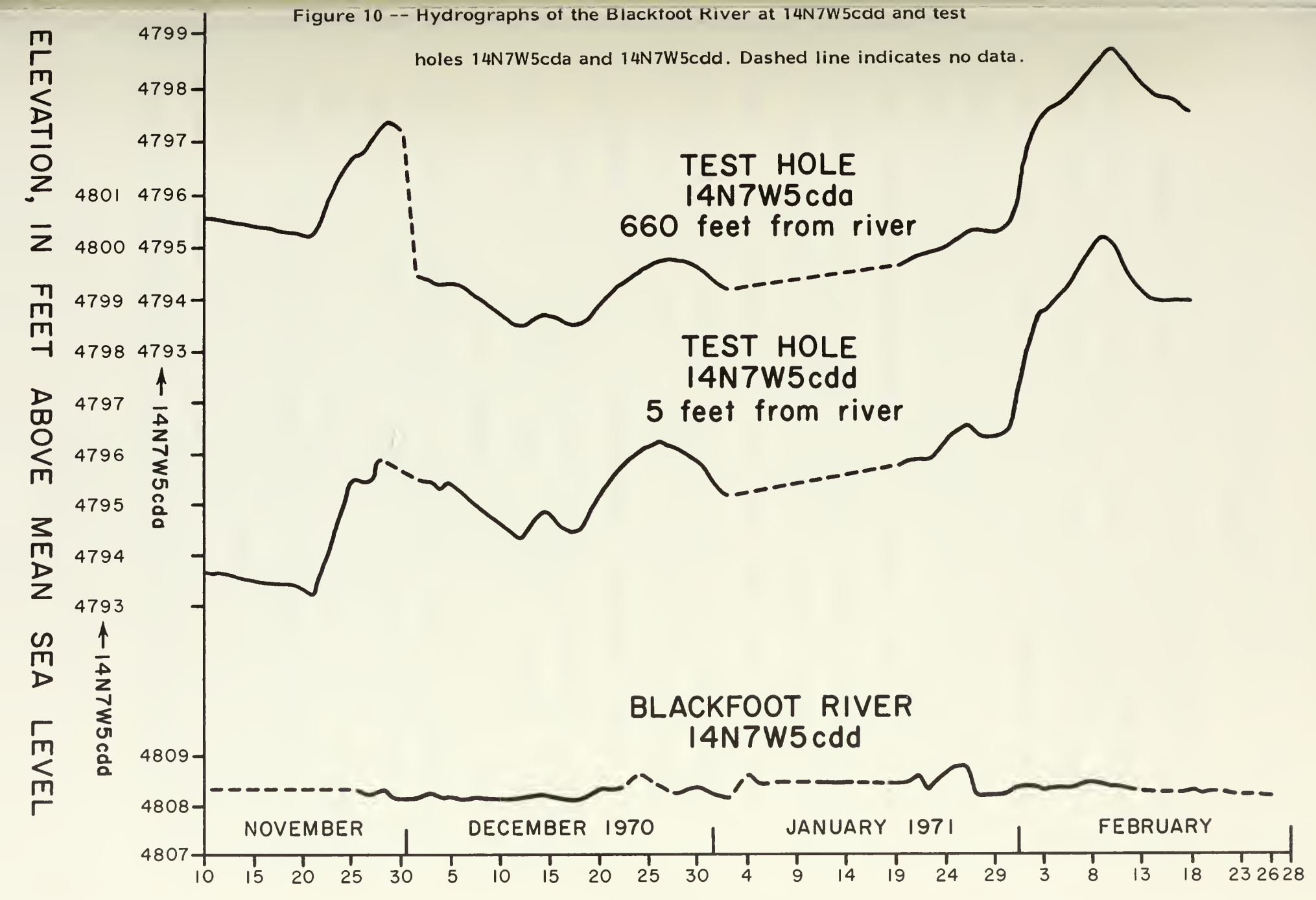
An estimate of the minimum amount of recharge to the alluvium from precipitation and from the poorly permeable rocks can be made from the streamflow record at 15N6W19adc. Water enters the alluvium, is temporarily stored, and eventually is discharged to the river or to the atmosphere. During the late fall and winter, surface runoff is small; therefore, the streamflow is mostly water discharged from

the alluvium. Streamflow averaged 3.2 cfs from October through March during water years 1969 and 1970 at 15N6W19adc. The drainage area upstream from this location is 15.1 square miles, thus the average recharge rate, over the entire basin, necessary to produce this streamflow is about one-fourth inch per month. If this rate is constant throughout the year, then about 15 percent of the annual precipitation recharges the alluvium and eventually becomes streamflow. This estimate of annual recharge is minimal because part of the recharge in the basin above the streamflow station reaches the stream downstream from the station and is not measured. Also, groundwater discharge from April through September is probably greater than the average rate from October through March.

The Blackfoot River recharges the alluvium between Flesher Lakes and Lincoln. A low-flow study on October 23, 1970, recorded a decrease in flow of 41.1 cfs between the mouth of the Landers Fork (4.9 river miles downstream from Flesher Lakes) and Lincoln, a distance of 6.6 river miles. The streamflow loss averages 6.2 cfs per mile. If this measured loss is representative of the average annual streamflow loss between Flesher Lakes and Lincoln, then about 52,000 acre-feet of water from the stream recharges the alluvium annually in this reach.

In addition to direct infiltration, the alluvium is recharged by water that has infiltrated into less permeable deposits and moved through these deposits to the alluvium. Most of the water reaching the alluvium in this manner has been recharge originally to basement rocks or to outwash and till. Because the basement rocks, outwash, and till are poorly permeable, the amount of water reaching the alluvium from these rocks is relatively small.

Figure 10 -- Hydrographs of the Blackfoot River at 14N7W5cdd and test holes 14N7W5cda and 14N7W5cdd. Dashed line indicates no data.



Water-level Fluctuations

Fluctuations of the water level in wells are measured principally to estimate changes in the volume of groundwater in storage or to aid in estimating the ability of the aquifer to store and transmit water. Changes in storage are estimated from records of at least one year of water-level fluctuations. Estimating the ability of the aquifer to store and transmit water from water-level fluctuations requires that the hydrologic system operates at least part of the time under conditions that can be approximated by mathematical models. The period for field data collection for this study (July 1970 -March 1971) was too short to estimate changes in storage, and hydrologic conditions were not conducive to developing meaningful mathematical models. To allow sufficient record to accumulate, water-levels in the test holes will be measured four times a year for several years. These data are available for public inspection in the U. S. Geological Survey office in Helena, Montana, and published periodically by the Montana Bureau of Mines and Geology.

Water-level fluctuations in the alluvium along the Blackfoot River near the mouth of Hogum Gulch are shown in figure 10. Test hole 14N7W5cdd is 5 feet north of the river bank and test hole 14N7W5cda is 660 feet north of the river bank. At this location the Blackfoot River is a losing stream, that is the elevation of the water table in the alluvium is lower than the elevation of the water surface of the stream, and water moves from the stream into the alluvium. Water-level fluctuations in the alluvium, however do not closely follow fluctuations of the stream. As shown in figure 10, the water level in the alluvium fluctuates as much as 6 feet while the maximum fluctuation of the river is less than a foot. Fluctuations in the alluvium decrease with distance from the stream. The water-level rise January 29 -

February 8, 1971, was 3.9 feet in the well 5 feet from the stream and 3.3 feet in the well 660 feet from the stream. Also, maximum water-level rise in the more distant well is almost a day later than the rise in the well nearer the stream. Because the maximum rise decreases in magnitude with distance from the stream and because the rise occurs later in time further from the stream, it appears that fluctuations in the alluvium may be related to stream fluctuations.

The cause-effect relationship between stream stage and water-level fluctuations in the alluvium, however, is unclear. Water-level fluctuations in alluvium usually are of less magnitude and mirror stream-stage fluctuations. Such is not true, however, in the alluvium along the Blackfoot River near the mouth of Hogum Gulch.

Movement

The direction of groundwater movement is determined by the hydraulic gradient. Movement is down the hydraulic gradient nearly at right angles to lines of equal elevation of the water table (water-table contours). For example, according to figure 9, water in the alluvium near the center of Lincoln travels west and is discharged into the Blackfoot River about a mile west of Lincoln, while the groundwater along the edge of the alluvial fill is discharged within 3 miles west of Lincoln. The elevation of the water table at any point depends on recharge, discharge, hydraulic characteristics of the aquifer, and the shape of and distance to the hydraulic boundaries of the aquifer.

Data are insufficient to draw water-table contours for the till, outwash, and basement rocks; however, the permeability of these deposits is low and the

Table 2 -- Result of low-flow studies on the Blackfoot River between 15N6W19adc and 14N9W28abb

	Aug. 19, 1970		Oct. 1, 1970		Oct. 23, 1970	
	Discharge (cfs)	Gain (+) Loss (-) (cfs)	Discharge (cfs)	Gain (+) Loss (-) (cfs)	Discharge (cfs)	Gain (+) Loss (-) (cfs)
Blackfoot River at 15N6W19adc	4.05		2.88			
Cadotte Creek near mouth	.89		0.0			
Blackfoot River at 15N7W23dcd	5.82	+0.88	5.56	+2.68		
Willow Creek near mouth	1.80		1.48			
Alice Creek near mouth	10.40		8.00			
Hardscrabble Creek near mouth	.91		.91			
Blackfoot River above mouth of Hogum Creek	21.27	+2.34	20.30	+4.36		
Blackfoot River above mouth of Landers Fork					15.2	
Landers Fork near mouth					36.1	
Blackfoot River at Lincoln					10.2	-41.1
Keep Cool Creek near mouth					17.1	
Poorman Creek near mouth					3.8	
Beaver Creek near mouth					3.6	
Blackfoot River at 14N9W28abb					103	+68.3

rate of groundwater movement through them is small. Where these occupy topographically higher positions than the alluvium in the Blackfoot valley, the water-table elevation is above the alluvium and water moves slowly from these deposits to the alluvium along the Blackfoot River.

According to figure 9, in general, water in the alluvium moves down the Blackfoot River valley and is discharged into the Blackfoot River in a reach 3 miles downstream from Lincoln. Flow is roughly parallel to the sides of the valley. Flow down the Blackfoot valley is interrupted in two places by "dams" of poorly permeable till and outwash. These "dams" are glacial moraines at Flesher Lakes and upstream from the mouth of Alice Creek (figure 5). They extend nearly across the valley and restrict the downstream movement of groundwater. Water in the alluvium is therefore forced to the surface immediately upstream from the dams and flows into the stream. Three miles downstream from Lincoln the valley narrows and the constriction causes water in the alluvium to flow into the stream.

Measured gains and losses of the stream are given in table 2. The gain in streamflow between 15N7W23dcd and the Blackfoot River above the mouth of Hogum Creek is caused by a gain between 15N7W23dcd and Flesher Lakes, because the stream loses water between Flesher Lakes and the mouth of Hogum Creek. If the Blackfoot River had been measured directly south of Flesher Lakes, the indicated streamflow gain between this point and 15N7W23dcd probably would have been greater than the amount shown in table 2 above the mouth of Hogum Creek.

The average interstitial velocity of groundwater movement varies directly with the hydraulic conductivity and the hydraulic gradient, and inversely with the effective porosity. The hydraulic conductivity estimated from pump tests on wells 14N7W5caa and 14N7W5cda ranges from 660 to 4,500 feet per day but probably

averages about 1,500 feet per day. The hydraulic gradient in the alluvium between Flesher Lakes and the mouth of the Landers Fork averages 0.0053 (28 feet per mile). The effective porosity is assumed to average 0.30. These average values of hydraulic conductivity, hydraulic gradient, and effective porosity result in an estimated average interstitial velocity of 26 feet per day. At this rate it would take a particle of groundwater about 200 days to travel 1 mile.

The volume rate of flow through a cross section of the alluvium is the product of the average hydraulic gradient, length of the saturated section of the alluvium normal to flow, and average transmissivity. The average hydraulic gradient through cross section D-D' (figure 6) is 0.0053, the length of the saturated section normal to flow is 2,700 feet, and the average transmissivity is assumed to be 46,000 square feet per day (table 1). These values result in an estimated volume rate of flow of 8 cfs through section D-D'.

Both the volume rate of flow and the interstitial velocity vary throughout the year because the hydraulic gradient varies in response to climatic changes. Estimated values presented in this report are based on data collected during the summer of 1970 and are, therefore, representative only during that period.

Discharge

In the study area, groundwater is discharged to streams and springs, and to the atmosphere by evapotranspiration. Discharge by wells is minimal and has little effect on the groundwater reservoir, even though most residents use water supplied by wells. Assuming that 500 people use groundwater and that the average daily use is 200 gallons per day per person, then about 100 acre-feet per year are pumped from wells. Probably more than half this water returns to the groundwater reservoir by seepage from cesspools, septic tanks, lawn watering, and garden irrigation. Lincoln has neither a municipal water system nor a municipal sewage system.

Groundwater is discharged to the Blackfoot River in three principal reaches in the study area--from near the headwaters downstream to 15N7W23dcd, from the mouth of Alice Creek downstream to Flesher Lakes, and from Lincoln downstream. Most groundwater in the study area is discharged to the river downstream from Lincoln. The length of stream channel that receives groundwater probably does not change greatly throughout the year; however, the rate of discharge to the stream varies in response to climatic changes. A series of accurate streamflow measurements would be needed to determine the annual groundwater discharge to the Blackfoot River. The rate of groundwater discharge (streamflow gain) in August and October 1970 is shown in table 2. If the streamflow gains in October as shown in table 2 are considered to represent average annual discharge rates, a tenuous assumption at best, then 54,000 acre-feet of groundwater are discharged annually to the river.

Groundwater is evaporated and transpired from water-table ponds and marshes and by vegetation growing where the water table is near land surface. The change

in evapotranspiration rates between August 19, 1970 and October 1, 1970, can be estimated from the change in streamflow gain (table 2). The drainage area between the measurement sites at 15N6W19adc and 15N6W23dcd includes about 400 acres in the valley bottom where the water table is within 5 feet of land surface and ponds and marshes cover about a fourth of the area. The weather was warm (70°F) on August 19, cool (50°F) on October 1, no significant precipitation had occurred for 2 weeks before either date, and streamflow was stable for a week before the measurements. Several killing frosts had occurred between the two measurements; therefore, the increased streamflow gain between the two sets of measurements (1.8 cfs) may be attributed to an increase in groundwater discharge to the stream caused by a decrease in evapotranspiration. The difference indicates an evapotranspiration rate in excess of 0.1 inch per day in August.

QUALITY OF WATER

A water-quality station was operated from October 1969 through September 1970 in conjunction with the streamflow station at 15N6W19adc and moved to 14N7W5cdd in October 1970. The results of field and laboratory analyses from the two surface water sites will be published by the U. S. Geological Survey office in Helena, Montana. Eight samples of groundwater were collected and analyzed during this study. Continued collection and analyses of samples from some of these sites may provide useful background data about the quality of groundwater. A report by Weisel and Newell (1970) describes the results of their sampling of water from the Blackfoot River from February 1968 to February 1969. Dale (1971) compiled the water-quality

data collected by the Montana Fish and Game Department from February 1968 to March 1970. These data define variations in natural quality of water and provide background that may be useful in determining changes that may result from an increase in man's activities.

Surface Water

A summary of the analyses for common constituents from samples collected at the station at 15N6W19adc is in table 3. Samples were collected daily between October 1, 1968, and September 30, 1970, and the specific conductance was determined. On the basis of specific conductance, one to three samples likely to represent extreme amounts of dissolved solids were selected each month and analyzed in the laboratory for common constituents. Field determinations were made monthly for dissolved oxygen, pH, and alkalinity. These data show that the water is of good chemical quality, which agrees with Weisel and Newell (1970, p. 13), who state "Although the total dissolved solids and the chemicals present in the Blackfoot River and its tributaries vary considerably, our analyses indicate that the streams are generally pure***."

Dissolved-solids concentration varies according to streamflow (figure 11). The highest concentrations occur during lowest flow. The principal constituents are calcium, magnesium, and bicarbonate. They are derived mostly from the solution of minerals in the rocks. When streamflow is made up mostly of groundwater discharge, the concentration of dissolved solids is relatively high, but when groundwater discharge is diluted by runoff from rain and snowmelt,

Table 3 -- Range of common constituents from water analyses of Blackfoot River at 15N6W19adc, water years 1969-70

Constituent	Units	Range
Silica (SiO_2)	mg/1	7.6--15
Dissolved iron (Fe)	ug/1	10--262
*Manganese (Mn)	ug/1	48--690
Calcium (Ca)	mg/1	9.0--39
Magnesium (Mg)	mg/1	4.1--12
Sodium (Na)	mg/1	0.7--5.6
Potassium (K)	mg/1	0.5--2.3
Bicarbonate (HCO_3)	mg/1	30--99
Carbonate (CO_3)	mg/1	0
Sulfate (SO_4)	mg/1	16--75
Chloride (Cl)	mg/1	0.0--2.2
Fluoride (F)	mg/1	0.0--0.2
*Nitrate (N)	mg/1	0.00--3.27
Nitrate (NO_3)	mg/1	0.0--0.3
Boron (B)	ug/1	0--110
Dissolved solids (residue at 180°C)	mg/1	65--204
Hardness (Ca, Mg)	mg/1	39--146
Noncarbonate hardness	mg/1	13--71
*Alkalinity as $CaCO_3$	mg/1	25--81
Sodium adsorption ratio		0.0--0.2
Specific conductance	micromhos at 25°C	91--295
pH	units	7.1--8.0
*Temperature	°C	0.0--15.5
Color	platinum-cobalt units	1--12

*1970 water year only

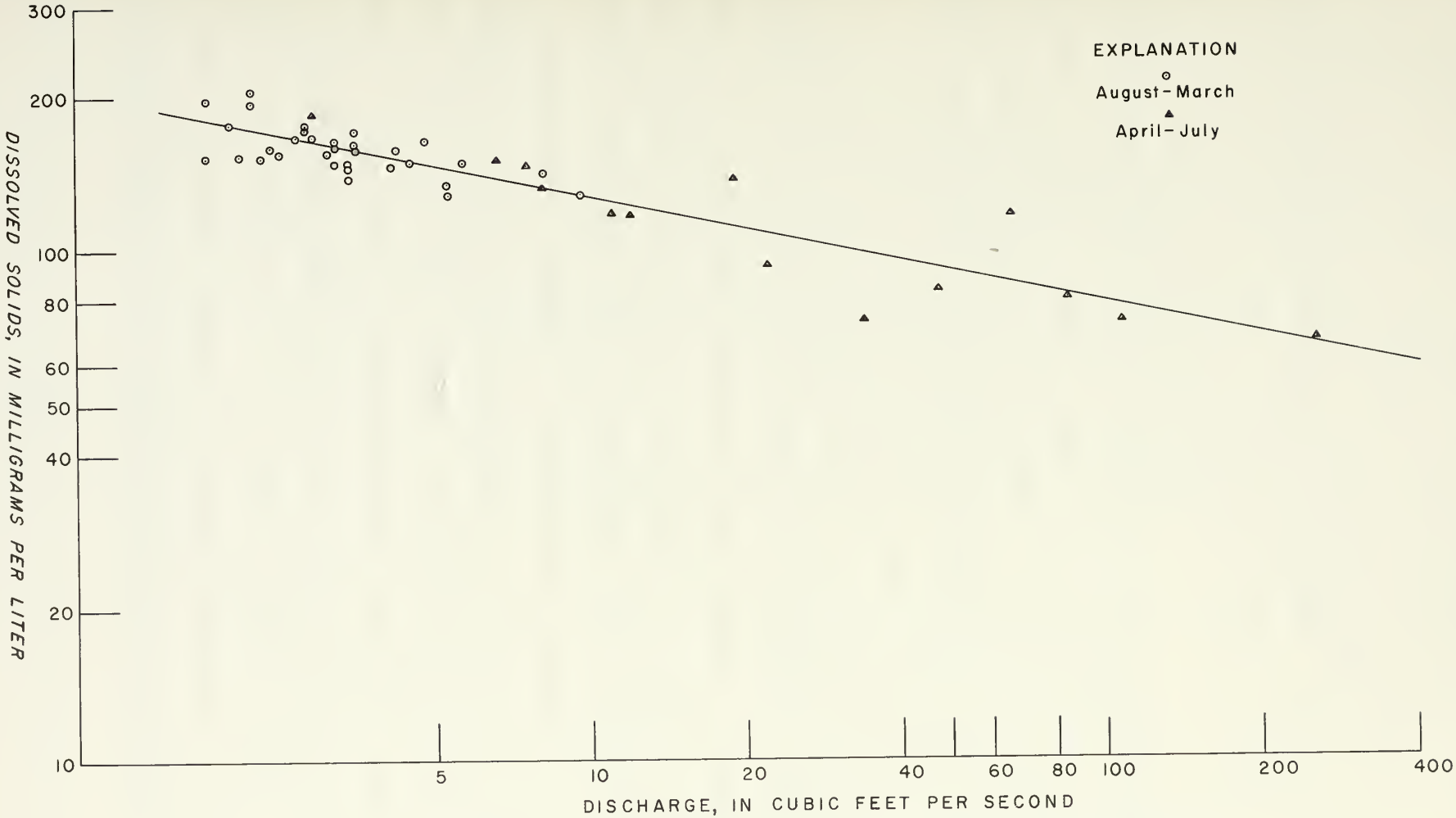


Figure 11 -- Relationship of dissolved solids and discharge in the Blackfoot River at 15N6W19adc, water years 1969-70.

the concentration of dissolved solids is low. Sulfate concentration is relatively high and varies in time as calcium, magnesium, and bicarbonate, which indicates that the concentration of sulfate is related to the amount of groundwater in the stream. Sulfate is commonly formed from the oxidation of sulfide minerals, which are present in the mineralized area upstream from 15N6W19adc. The sulfur in sulfide minerals such as pyrite (FeS_2) of chalcopyrite ($CuFeS_2$) is oxidized to sulfate (SO_4^{-2}) ions and carried off in the water.

Concentrations of minor constituents dissolved in water are given in table 4. Comparison of the analyses show that, except for silver, the concentrations are smaller at location 14N7W5cdd than at 15N6W19adc. Streamflow is greater at 14N7W5cdd, thus the smaller concentrations at 14N7W5cdd mainly result from dilution. Also, the station at 15N6W19adc probably is closer to the source of the minor constituents and the constituents dissolved in the water at this location may be changed by some process before reaching location 14N7W5cdd. Minor constituents could be precipitated, absorbed on sediment particles, or combined with organic material. These processes might not necessarily physically remove the constituents from the water, but could change their condition so that they would not be determined in an analysis for dissolved minor constituents.

Variations in dissolved oxygen concentrations over a 24-hour period were measured four times in the summer and fall. The results are shown in figure 12. Included for comparison is the calculated saturation concentration of dissolved oxygen. Dissolved-oxygen content ranged from 85 to almost 100 percent of saturation. In summer the variations in the oxygen content correspond to changes in air and water temperatures. Apparently, not enough plants grow in the water to cause the oxygen content to increase significantly because of photosynthesis.

Table 4 -- Results of chemical analyses for minor constituents dissolved in water from the Blackfoot River
Concentrations in micrograms per liter

Location	15N6W19adc					14N7W5cdc
	Sept. 9, 1968	Oct. 10, 1968	Nov. 7, 1968	Mar. 11, 1969	Aug. 22, 1969	Oct. 15, 1970
Streamflow (cfs)	--	5.3	3.1	2.2	4.8	21
Aluminum (Al)	23	17	19	--	23	53.62
Arsenic (As)	--	--	--	--	--	.00
Barium (Ba)	140	120	100	--	170	.00
Beryllium (Be)	.6	1	1	--	2	.00
Bismuth (Bi)	3	6	3	--	6	----
Boron (B)	13	7	20	--	1	2.92
Cadmium (Cd)	30	11	52	--	55	.00
Chromium (Cr)	3	4	2	--	5	.00
Cobalt (Co)	3	6	3	--	6	.00
Copper (Cu)	7	9	7	--	6	.00
Germanium (Ge)	--	6	5	--	6	----
Iron (Fe)	24	20	10	--	20	2.11
Lead (Pb)	3	3	2	--	3	.00
Lithium (Li)	2	1	1	--	2	----
Manganese (Mn)	180	200	260	450	140	.00
Molybdenum (Mo)	.6	1	2	--	1	1.00
Mercury (Hg)	--	--	--	--	--	.00
Nickel (Ni)	3	3	5	--	4	.00
Rubidium (Rb)	2	1	1	--	0	.00
Selenium (Se)	--	--	--	--	--	.00
Silver (Ag)	0	0	0	--	0	1.00
Strontium (Sr)	60	60	67	--	75	----
Tin (Sn)	6	6	3	--	6	----
Titanium (Ti)	3	4	1	--	3	----
Vanadium (V)	3	4	2	--	3	.30
Zinc (Zn)	450	500	550	--	450	20.00

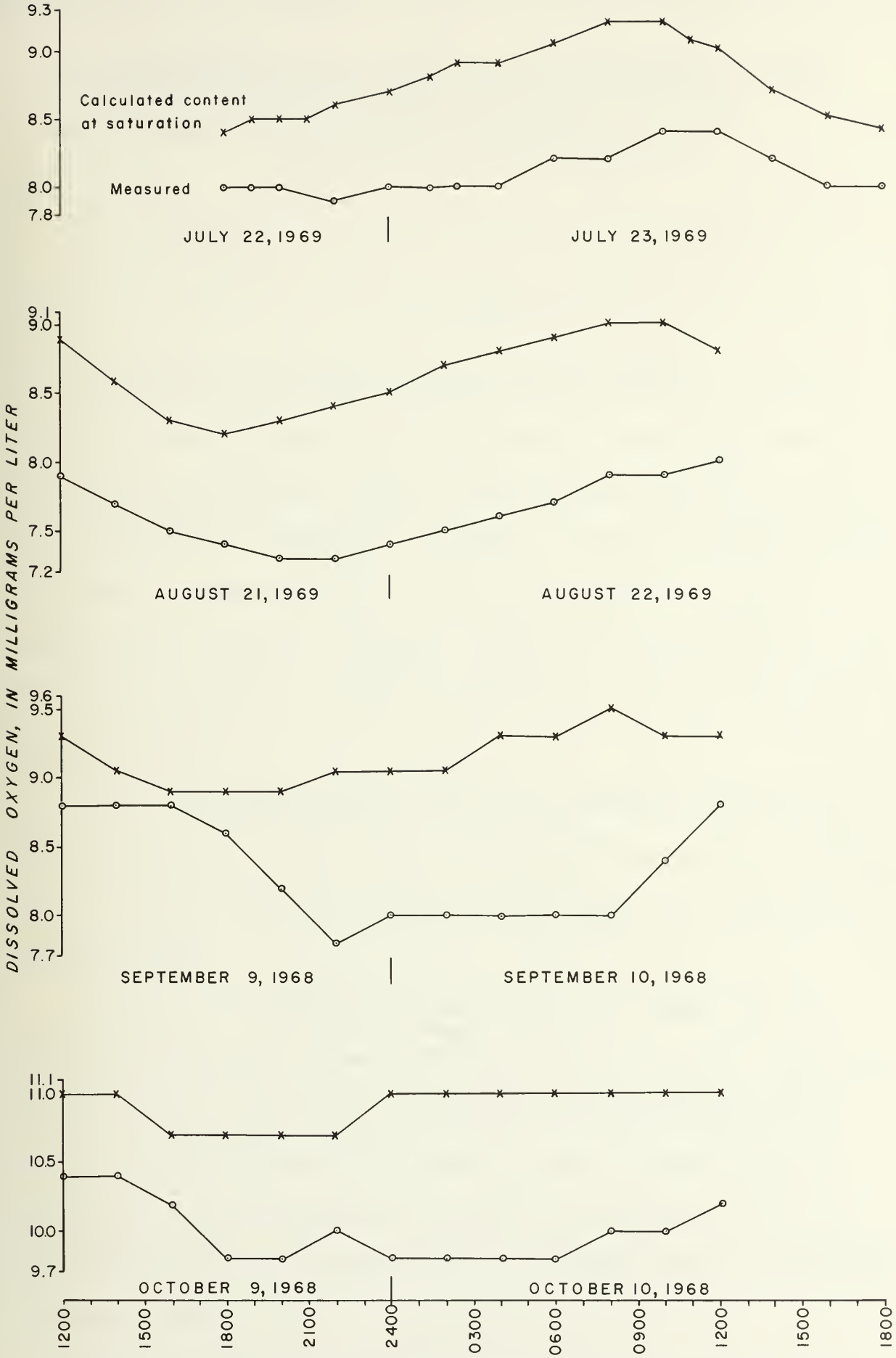


Figure 12 -- Comparison of the concentration of dissolved oxygen in the Blackfoot River at 15N6W19adc with the calculated saturation concentration of dissolved oxygen.

During the fall the variations in oxygen content are smaller than in summer because variations in water temperature were smaller.

Groundwater

Chemical analyses of dissolved constituents in groundwater are given in table 5. Calcium, magnesium, and bicarbonate are the principal constituents. The high iron concentrations in water from the Tertiary(?) sediments from test holes 14N7W5cda and 14N7W5cdd were caused by solution of suspended particles of pyrite and magnetite when acid was added to the samples in the field. The samples were collected at the completion of the test drilling and were not filtered. The iron concentration as reported is not representative of water from the Tertiary(?) sedimentary rocks.

The concentration of dissolved solids in groundwater is about equal to that of surface water having the highest values of dissolved solids. Thus, during periods of medium to high streamflow surface water contains less dissolved solids than groundwater.

Analyses of six unfiltered groundwater samples for copper, lead, and zinc revealed an average concentration of copper and zinc of about 10 ug/1 (micrograms per liter). Two samples of water from the alluvium contained 40 ug/1 of lead; no lead was reported in the other four samples. These data must be substantiated by future sampling and analyses before conclusions can be made about the amounts of minor constituents that are normally present in groundwater in the study area.

PROPOSED DEVELOPMENTS ASSOCIATED WITH THE PROPOSED MINING OPERATION

The next two paragraphs of the report and figure 13 are abstracted from a statement presented by Douglas G. Smith, Director of the Montana Water Resources Board at a public briefing in Helena, Montana, March 18, 1970. Mr. Smith's statement describes preliminary plans made by The Anaconda Co. for mining operations in the area. Parts of the plans have been subsequently modified and the modifications as known by the authors are included in these paragraphs. The principal modifications reduce the original considered production rate of 30,000 tons per day to 15,000 tons per day or less and cancel plans for a reservoir in the Alice Creek valley.

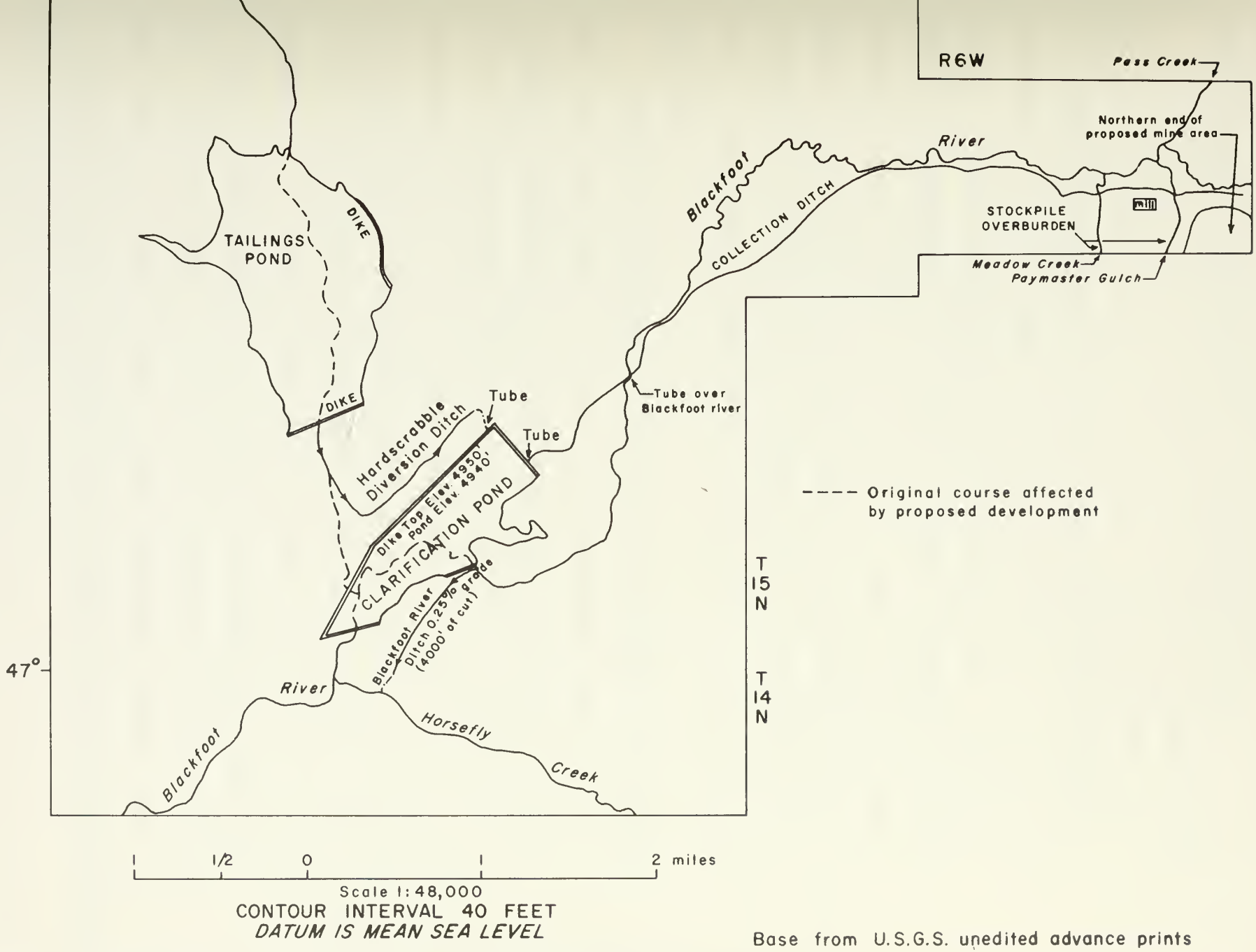
The mine area is east of Paymaster Gulch (figure 13), and the mill is tentatively planned to be between Paymaster Gulch and Meadow Creek. Overburden from the mine is to be stockpiled in Paymaster Gulch and Meadow Creek. A collection ditch to intercept runoff from the stockpiles and mine area will extend from the mine to a clarification pond in the Blackfoot Valley 5 miles downstream. The Blackfoot River would be diverted around the clarification pond by a ditch about 4,000 feet long. Bartlett and Alice Creeks would be diverted around the north side of the clarification pond into the Flesher Lakes area. Hardscrabble Creek would be diverted into the clarification pond.

A slurry of mill tailings will be carried in pipelines from the mill to the tailings pond where the tailings will separate from the water. The water will be carried back to the mill in another pipeline for re-use. Most of the water used at the mill may be diverted from the Blackfoot River or its tributaries or

Table 5. -- Results of chemical analyses of water from wells and springs in the upper Blackfoot River drainage. Analyses by Montana Bureau of Mines and Geology (All constituents reported in milligrams per liter except as indicated.)

Location	Test hole--depth or elevation of sample point (feet)	Geologic source	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids[1/] (calculated)	Hardness as $CaCO_3$		Total alkalinity as $CaCO_3$	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH (units)	Copper (Cu)	Lead (Pb)	Zinc (Zn)
																	Carbonate	Noncarbonate							
14N7W5cda[2/]	160	Tertiary(?) sediments and alluvium	8-10-70	8.1	4.88	0.50	26	14	---	132	0	16	0.7	0.1	1.9	203	108	12	108	---	208	8.21	----	----	----
14N7W5cdd2[3/]	200	Tertiary(?) sediments	8-10-70	7.6	4.95	.35	29	12	---	140	0	10	.4	.0	1.9	206	114	6	115	---	229	8.88	----	----	----
14N7W5cac	76	Alluvium	10-16-70	8.5	.12	.01	39	13	5.0	185	0	6	2.1	.0	1.4	261	152	2	152	0.1	267	7.67	0.01	0.00	0.03
14N7W5cda	160	Alluvium	10-16-70	5.3	.06	.01	31	12	3.3	149	0	15	.1	.0	.0	216	122	4	122	.1	247	8.10	.01	.04	.01
14N7W5cdd2	200	Alluvium	10-14-70	4.4	.15	.01	27	98	2.6	123	0	17	.5	.0	1.0	185	101	5	101	.1	175	8.10	.01	.04	.01
15N7W28abb	130	Basement rocks	10-17-70	9.6	.19	.01	30	15	6.3	184	0	2	1.0	.0	1.1	249	136	0	151	.2	286	8.30	.01	.00	.01
15N7W21dcc	5,010	Alluvium	10-17-70	4.0	.02	.01	32	17	3.2	176	0	9	.2	.0	1.1	241	144	4	144	.1	218	8.20	.01	.00	.01
15N7W35bd	5,050	Till	10-15-70	9.8	.02	.01	57	15	4.1	227	0	6	.8	.0	1.4	318	186	5	186	.1	353	8.18	.01	.00	.01

1/ Calculated as the sum of constituents
2/ Sample from interval between 100 feet and 160 feet
3/ Sample from interval between 160 feet and 200 feet



Base from U.S.G.S. unedited advance prints

Figure 13 -- Location of proposed mining developments.

may be pumped from wells. The Anaconda Co. estimates that 1 ton (32 cubic feet) of water is needed for each ton of ore processed in the mill.

The Anaconda Co. plan as described by Mr. Smith would separate mine and mill waste water from water in the streams. Because these waters are to be separated and because mine and mill waste water would eventually be evaporated or recycled, surface water contamination should be minimal or be averted as long as the developments operate according to plan. Barring any unforseen circumstances, and assuming the proposed developments are properly constructed, the principal way for water that has been in contact with waste material to enter the hydrologic system appears to be by seepage from the clarification pond, tailings pond, or collection ditch. If contaminants reach the groundwater reservoir they could eventually reach the stream or be pumped from wells.

The rate of groundwater flow depends upon the permeability of the rocks and the hydraulic gradient. The total flux of groundwater depends on the permeability, gradient, and the area through which water flows. If the total flux of groundwater from a pond or ditch is to be reduced, then the factors controlling groundwater flow need to be decreased. Permeability may be decreased by lining the ditch or pond with a layer of clay-sized material such as "bentonite," plastic, asphalt, concrete, or some other nearly impermeable material. The hydraulic gradient may be minimized by keeping the elevation of the water level in a pond or ditch as close as possible to the elevation of the adjacent water table. The area through which water may infiltrate can be minimized by keeping the wetted area of the pond or ditch as small as possible. Generally, infiltration from ponds or ditches can be kept at a minimum if they are located in areas where the permeability and hydraulic gradient are small.

Comparison of figures 13 and 9 show that the proposed location for the tailings pond and most of the length of the collection ditch are in areas where poorly permeable rocks are at the surface. Leakage from the ditch might be expected to be greatest where the more permeable sediments are exposed westward from the mine for about a mile. Potential leakage in the areas proposed for the ditch and tailings pond could be reduced by lining the ditch and pond.

The proposed location for the clarification pond is on alluvium where the water table is near land surface. Test holes 15N7W33dcb and 15N7W33dcd were drilled near the west end of the proposed location of the pond. The logs of these test holes indicate the upper part of the alluvium is composed of sand, gravel, silt, and clay, and that the upper part of the alluvium is a poor aquifer. Except at the two test holes, however, the permeability of the alluvium underlying the proposed location has not been determined. Because the permeability of the alluvium is one of the factors that governs the infiltration rate from a pond, the permeability should be determined in order to estimate the possible infiltration.

Data necessary to estimate the permeability of the alluvium beneath the proposed location of the clarification pond would include test-hole logs, pumping tests, and infiltration tests. At least three test holes and three pumping tests would be necessary because the lithologic and hydrologic properties of the alluvium may differ throughout the area proposed for the pond. Infiltration tests should be made of the various mixtures of sand, gravel, silt, and clay that are exposed and should include the sand and gravel exposed in the stream channel.

If the data indicate that the proposed pond may leak, and if the chemical quality of the water intended for the pond is such that the leakage could contaminate groundwater in the alluvium, then special precautions may be necessary to reduce

leakage from the pond. The most obvious precaution would be to change the proposed location of the pond to an area underlain by less permeable material. If it is infeasible to change the proposed location, it may be possible to line the pond with a layer of clay-sized material, asphalt, plastic, or a combination of two or more layers. As a further precaution, the area of the pond should be as small as possible without greatly increasing the height of the dike (the higher the dike, the greater the hydraulic gradient from the pond to the water table).

SUMMARY AND CONCLUSIONS

Rocks in the study area are grouped into six units based on their gross lithologic features and their hydrologic properties. These units are basement rocks, Tertiary(?) sedimentary rocks, till, outwash, lakebed deposits, and alluvium. Alluvium is the most permeable unit and is of greatest importance to the groundwater system. Tertiary(?) sedimentary rocks and basement rock contain zones that are capable of yielding at least 0.5 cfs to wells; however, compared to the alluvium these units are of minor hydrologic significance. The other units--till, outwash, and lakebed deposits--are either nearly impermeable or poorly permeable and would yield only 0.01 to 0.02 cfs to wells or springs. These units serve to inhibit or restrict the movement of groundwater.

Alluvium is recharged directly or indirectly by precipitation. A small percentage of the precipitation falling directly on the alluvium reaches the water table, and smaller amounts reach the alluvium by seepage through the adjacent less permeable rocks. The Blackfoot River recharges the alluvium between Flesher Lakes and Lincoln. Water in the alluvium flows down the valley. The interstitial velocity in the Hogum Creek area is roughly 26 feet per day and the volume rate of flow through a cross section near the mouth of the creek is roughly 8 cfs. The flow is interrupted by two "dams" of till and outwash upstream from the mouth of Alice Creek and at Flesher Lakes. These "dams" force water in the alluvium to the surface where it is discharged into the stream. Groundwater is discharged from the alluvium to the Blackfoot River upstream from the two "dams", and in a 3-mile reach downstream from Lincoln and by evapotranspiration.

Surface water and groundwater are of good quality. From October 1969

through September 1970, dissolved solids in the Blackfoot River ranged from 65 mg/1 to 204 mg/1 depending on stream discharge. Dissolved solids in groundwater range from 185 mg/1 to 318 mg/1 and probably do not vary greatly in time. Both surface water and groundwater contain mainly calcium, magnesium, and bicarbonate. Water samples from the Blackfoot River at 15N6W19adc contain higher concentrations of dissolved minor constituents (heavy metals) than water from the river at 14N7W5cdd. The downstream decrease in dissolved minor constituents indicates that they are diluted by increased discharge or that they are removed from solution.

Mining operations proposed by the Anaconda Co. in the upper Blackfoot River drainage include plans to keep surface water that has contacted mine waste separated from streams and to use this water for milling. Assuming proper construction and proper execution of the plans, the greatest chance for contamination of the hydrologic system in the upper Blackfoot valley will be by seepage into and out of the groundwater reservoir. The tailings pond and most of the collection ditch are planned to be on deposits of relatively low permeability. Thus, seepage to the groundwater reservoir would not be expected to be large but could be reduced further by lining these areas. The proposed location of the clarification pond is on alluvium where the water table is near land surface. More testing in this area is needed to determine the possible infiltration rate from the pond. If the tests indicate that the proposed pond may leak and if the chemical quality of the water intended for the pond is such that the leakage could contaminate the groundwater in the alluvium, then special precautions may be necessary to reduce leakage from the pond.

SUGGESTIONS FOR CONTINUING STUDY

As is true in many hydrologic studies, some questions remain unanswered. Excluding the question, which has been previously discussed, of determining the permeability of the area proposed for the clarification pond, three of the principal questions are: 1) How effective are the "dams" of till and outwash that partly block the Blackfoot valley at Flesher Lakes and upstream from the mouth of Alice Creek? 2) What is the chemical quality of the water and what are its variations with time? and 3) Will the plan proposed by The Anaconda Co. prevent contamination of the hydrologic system? The need for these questions to be answered, of course, depends on whether or not the mineral resources in the upper Blackfoot basin are developed. If these resources are to be developed, hydrologic data should continue to be collected to provide answers to the above questions.

The first question may need to be answered because if the natural "dams" are effective, and they appear to be, then they isolate the alluvium along the Blackfoot River into three sections. Groundwater in each section seems to behave independently of the other sections. If true, this would make management of groundwater in each section much easier. The effectiveness of the dams could be evaluated by deepening test hole 15N7W23dcc2 to the basement rocks and by drilling one or two test holes to the Tertiary(?) sedimentary rocks at the "dam" at Flesher Lakes. If permeable rocks are found beneath the till at either location, pumping tests should be conducted.

The second and third questions can be answered in part by continuing to collect streamflow and quality of water data at 14N7W5cdd. This station is

almost 2 miles downstream from the area considered for development and should detect any contaminated surface water leaving the area. The chemical quality of groundwater leaving the area proposed for development could be determined by semiannual sampling of four test holes near 14N7W5cdd (line D-D', figure 6). Analysis of the samples collected near 14N7W5cdd will determine the quality of water flowing from the area proposed for development; however, if contamination is detected there, additional sampling will be necessary to determine where it is entering the system. To provide the background data necessary to detect contamination in the area, the following items are suggested in addition to semiannual samples near 14N7W5cdd:

1) Re-establish the streamflow and quality of water station at 15N6W19adc.
2) Measure water levels four times a year in all test holes drilled by the U. S. Geological Survey and by the Anaconda Co.
3) Collect samples for chemical analysis, semiannually, from test holes 15N6W20cba, 15N7W21cbb, 15N7W24abc, 15N7W27bda, 15N7W28abb, 15N7W33dcd, 15N7W33dcb, and test hole 15N7W23dcc2 if it is deepened.
4) Continue study of the new data and collect supplemental data as the studies indicate.

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APPENDIX

GLOSSARY

Most of the following definitions are based on those in the "Dictionary of Geological Terms" prepared under the direction of the American Geological Institute (1962), those in Lohman and others (1970), and those in Langbein and Iseri (1960).

Bailing--Process for removing water from a well by lowering and raising a bailer. The bailer is a section of pipe with a check valve at the bottom.

Belt Supergroup--A formal name for a thick sequence of rock formations more than 570 million years old.

Discharge--The outflow of water.

Drawdown--Lowering of the water in a well by withdrawing water from it or from another well.

Evapotranspiration--Water withdrawn from a land area by evaporation from water surfaces and moist soil and by plant transpiration.

Glaciolacustrine--Pertains to a lake formed between the margin of a glacier and an encircling rim of hills due to the damming of the natural drainage.

Head, static--The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the pressure at a given point.

Hydraulic conductivity--A measure of the ability of a cross section of unit area of a porous medium to transmit water, expressed as unit length per unit time.

Hydraulic gradient--The change in static head per unit of distance in a given direction.

Igneous rock--A rock formed by solidification from a molten or partially molten state. If the molten rock solidified below the surface of the earth, the rock is called an intrusive igneous rock and if solidification was above the surface, the rock is

called extrusive.

Moraine--Rock material deposited chiefly by glacial action, and having construction topography independent of control by the surface on which it lies. Lateral moraines are formed along the sides of a glacier and terminal moraines at the ends.

Nonsteady flow--Flow when the magnitude or direction of flow through a unit cross-sectional area changes with time.

Permeability--A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

Reach--Any length of a river.

Recharge--Water that moves into the zone of saturation.

Sill--An intrusive body of igneous rock of approximately uniform thickness and relatively thin compared with its lateral extent, which has been emplaced parallel to the bedding of the intruded rocks.

Specific yield--The ratio of the volume of water which, after being saturated, a rock will yield by gravity to its own volume.

Storage coefficient--The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Streamflow--The discharge that occurs in a natural channel.

Streamflow station--A place on a stream where a daily record of discharge is obtained.

Surging--The process of reversing the direction of flow through openings in a well casing. Surging can be done by operating a plunger up and down in a casing.

Transmissivity--The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Usually expressed in units of length cubed per unit time per unit length, which reduces to units of length squared per unit time.

Tuff--A rock formed of compacted volcanic fragments, generally smaller than 4 millimeters in diameter.

Welded tuff--A tuff which has been indurated by the combined action of the heat retained by the particles and the enveloping hot gasses.

Table 6 -- Record of wells and springs

Explanation

Well number:	See Test for description of well-numbering system.
Type of well:	Dn, driven; Dr, drilled.
Type of casing:	P, steel pipe.
Use of water:	D, domestic; F, fire protection, In, industrial; Ir, irrigation; N, not being used; O, observation of water-level fluctuation.
Elevation of land surface:	Expressed in feet above sea level and obtained by instrumental leveling and from topographic maps.

TABLE 6 - RECORD OF WELLS AND SPRINGS

WELL NUMBER	OWNER OR TENANT	YEAR DRILLED	TYPE OF WELL	DEPTH OF WELL (FEET)	DIAMETER OF WELL (INCHES)	TYPE OF CASING	USE OF WATER	ELEVATION OF LAND SURFACE	DEPTH OF WATER BELOW LAND SURFACE (FEET)	DATE OF MEASUREMENT
14N7W5cac	U.S. Geological Survey	70	Dr	76	-	P	O	4821.39	20.16	7-07-70
14N7W5cda	U.S. Geological Survey	70	Dr	160	-	P	O	4817.43	16.70	8-06-70
14N7W5cdd	U.S. Geological Survey	70	Dr	55	-	P	O	4811.83	9.24	7-29-70
14N7W5cdd2	U.S. Geological Survey	70	Dr	200	-	P	O	4814.39	18.73	8-06-70
14N7W7dbc	U.S. Forest Service	--	Dr	--	6	P	N	4773	9.89	7-22-70
14N8W11dcd	D. Martin	70	Dr	82	6	P	D	4738	45.60	8-31-70
14N8W12abc	Delaney Sawmill	--	Dn	--	-	P	In	4782	8.99	7-22-70
14N8W12acb	do.	--	Dn	--	-	P	D	4779	10.24	7-22-70
14N8W14cab	7 Up Ranch	--	Dn	--	-	P	F	4695	10.48	7-22-70
14N8W16cda	Vern Yearhammer	--	Dn	--	-	P	-	4627	5.77	7-22-70
14N8W16dac	Sy Sprott	--	Dn	--	-	P	-	4638	8.89	7-22-70
14N8W20aab	Ken Hoeffner	--	Dn	--	-	P	-	4606	7.41	7-22-70
14N8W20bab	Blackfoot Post Yard	--	Dn	10.3	2	P	D	4599	4.3	8-25-70
14N9W24aaa	Iron Ingalls	--	Dn	8	2	P	Ir	4560	3.7	8-23-70
14N9W24aac	Lincoln School	69	Dn	15	2	P	F	4552	10.2	8-24-70
14N9W24aca	Tubbs	--	Dn	16	2	P	F	4550	8.7	8-24-70
14N9W24acd	Anderson	51	Dn	15	2	P	F	4550	6.7	8-24-70
14N9W24acd2	Newby	--	Dn	13	2	P	F	4450	4.7	8-24-70
14N9W24bcc	Arthur Parson	--	Dn	10.0	2	P	Ir	4530	6.3	8-23-70
14N9W24caa	Lambkins	--	Dn	13.5	2	P	-	4542	8.3	8-25-70

TABLE 6 - RECORD OF WELLS AND SPRINGS

WELL NUMBER	OWNER OR TENANT	YEAR DRILLED	TYPE OF WELL	DEPTH OF WELL (FEET)	DIAMETER OF WELL (INCHES)	TYPE OF CASING	USE OF WATER	ELEVATION OF LAND SURFACE	DEPTH OF WATER BELOW LAND SURFACE (FEET)	DATE OF MEASUREMENT
14N9W24dba	Gerald Hemmer	--	Dn	14.1	2	P	F	4548	6.1	8-24-70
14N9W24dbb	Gene Tinsley	--	Dr	29.1	6	P	D	4544	4.1	70
14N9W28aad	Hueth	--	--	33	6	P	D	4470	3.4	8-23-70
15N6W20cba	The Anaconda Co.	70	Dr	65	10	P	O	5145.1	4.28	6-13-70
15N6W20daa	The Anaconda Co.	70	Dr	53	10	P	O	5202.1	4.78	6-17-70
15N7W28abb	U.S. Geological Survey	70	Dr	130	-	P	O	5032.32	1.32	8-19-70
15N7W16ccc	U.S. Geological Survey	70	Dr	98	-	P	O	5139.1	26.74	8-14-70
15N7W21cbb	U.S. Geological Survey	70	Dr	263	-	P	O	5089.9	24.04	8-25-70
15N7W23dcc	U.S. Geological Survey	70	Dr	122	-	P	O	5093.2	70.13	10-20-70
15N7W23dcc2	U.S. Geological Survey	70	Dr	105	-	P	O	5058.3	4.87	8-26-70
15N7W24abc	The Anaconda Co.	70	Dr	126	10	P	O	5083.1	5.94	6-12-70
15N7W24baa	The Anaconda Co.	70	Dr	118	6	P	O	5075.0	2.05	6-18-70
15N7W33dcd	The Anaconda Co.	70	Dr	108	10	P	O	4879.5	4.02	6-10-70
15N7W27abc	The Anaconda Co.	70	Dr	22	8	P	O	4995	no water	6-20-70
15N7W27bda	The Anaconda Co.	70	Dr	94	8	P	O	4980.3	38.46	6-21-70
15N7W28dcb	The Anaconda Co.	70	Dr	98	8	P	O	4957.6	+12	6-20-70
15N7W33dcb	The Anaconda Co.	70	Dr	129	8	P	O	4876.5	3.94	6-15-70

Table 7 -- Logs of test holes

Sample descriptions of the U.S. Geological Survey test holes are by D.L. Coffin; other descriptions are by The Anaconda Company.

14N7W5cac. U. S. Geological Survey test hole A-1; land surface elevation 4,821.39 feet; perforated 61-71 feet, open hole 73-76 feet; water level July 7, 1970 was 20.16 feet below land surface.

	Thickness (feet)	Depth (feet)
Alluvium:		
Sand, medium to very coarse, and very fine to medium gravel; contains silt and clay.....	6	6
Gravel, very fine to medium, and very fine to very coarse sand; contains a little silt and clay. Gravel and very coarse sand are subrounded to rounded red quartzite and red argillite.....	19	25
Sand, fine to very coarse, angular to subrounded, and very fine to fine gravel; contains silt, fragments of volcanic glass, and a few cobbles.	11	36
Gravel, very fine to very coarse, subrounded to rounded, and very fine to very coarse subrounded sand; contains cobbles.....	4	40
Sand, very fine to very coarse, and light-reddish clay; contains silt and very fine to medium gravel.....	33	73
Basement rocks:		
Argillite, light-red, drills hard.....	3	76

14N7W5cac. U. S. Geological Survey test hole A-1; land surface elevation 4,821.39 feet; perforated 61-71 feet, open hole 73-76 feet; water level July 7, 1970 was 20.16 feet below land surface.

	Thickness (feet)	Depth (feet)
Alluvium:		
Sand, medium to very coarse, and very fine to medium gravel; contains silt and clay.....	6	6
Gravel, very fine to medium, and very fine to very coarse sand; contains a little silt and clay. Gravel and very coarse sand are subrounded to rounded red quartzite and red argillite.....	19	25
Sand, fine to very coarse, angular to subrounded, and very fine to fine gravel; contains silt, fragments of volcanic glass, and a few cobbles.	11	36
Gravel, very fine to very coarse, subrounded to rounded, and very fine to very coarse subrounded sand; contains cobbles.....	4	40
Sand, very fine to very coarse, and light-reddish clay; contains silt and very fine to medium gravel.....	33	73
Basement rocks:		
Argillite, light-red, drills hard.....	3	76

14N7W5cda. U. S. Geological Survey test hole A-2; land surface elevation 4,817.43 feet; perforated 40-50 feet, 60-75 feet, 85-95 feet, open hole 100-160 feet; water level Aug. 6, 1970 was 16.70 feet below land surface.

	Thickness (feet)	Depth (feet)
Topsoil:		
Sand, fine to coarse, rounded, and silt: dark-brown	5	5
Alluvium:		
Gravel, very fine to medium, subrounded to rounded, and medium to very coarse sand. Larger grains are mostly red argillite and light-brown quartzite	1	6
Gravel, very fine to coarse, subrounded to rounded, and very fine to very coarse sand; contains reddish-brown clay and silt. Larger grains are mostly argillite and quartzite	12	18
Clay, silty, light-reddish-brown, and very fine to medium sand; contains a little very fine gravel	2	20
Gravel, very fine to coarse, subrounded to rounded and very fine to very coarse sand; contains reddish-brown clay and silt. Larger grains are mostly argillite and quartzite	11	31
Sand, medium to very coarse, angular to sub-rounded; contains very fine gravel	4	35
Gravel, very fine to very coarse, subrounded to rounded, and very fine to very coarse sand. Larger grains are mostly red argillite	17	52
Clay, sandy, red; contains very fine to fine gravel	3	55
Gravel, very fine to very coarse, subrounded to rounded, and medium to very coarse sand. Larger grains are mostly red argillite and light-brown quartzite	24	79
Sand, very fine to very coarse, subrounded to rounded; contains coarse rounded grains of rusty weathered igneous rock	3	82
Gravel, very fine to fine, subrounded to rounded, and medium to very coarse sand; contains silt and clay. Larger grains are mostly red argillite and light-brown quartzite	13	95

14N7W5cda. -- continued

	Thickness (feet)	Depth (feet)
Tertiary(?) sediments:		
Clay, sandy, light-brown, and layers of very fine to fine subrounded to rounded gravel. Gravel is composed of sandstone, argillite, and black igneous rocks.....	10	105
Clay, sandy, light-gray, and layers of fine to very coarse, subrounded to well-rounded sand; contains thin layers of very fine gravel. Sand is mostly grains of quartz and volcanic glass; contains abundant euhedral crystals of pyrite and dark minerals occur as inclusions in sand grains.....	50	155
Limestone, silty, light-pinkish-brown; pyrite crystals are scattered through limestone.....	5	160

14N7W5cdd. U. S. Geological Survey test hole A-3; land surface elevation 4,811.83 feet; perforated 10-25 feet, 45-55 feet; water level July 29, 1970 was 9.24 feet below land surface.

	Thickness (feet)	Depth (feet)
Alluvium:		
Cobbles, well rounded, and medium to very coarse gravel; contains clay, silt, and sand. Cobbles and gravel are mostly red argillite and light-pink quartzite	12	12
Gravel, very fine to very coarse, and very fine to very coarse sand; contains light-red clay and silt. Larger grains are mostly red argillite and light-pink quartzite	17	29
Sand, very fine to very coarse, angular to subrounded, and very fine to fine gravel; contains silt	24	53
Boulder(?), poor sample; composed mostly of fragments of red argillite and light-brownish-red rhyolite. Unable to drill further	2	55

14N7W5cdd2. U. S. Geological Survey test hole A-4; land surface elevation 4,814.39 feet; perforated 40-50 feet, 60-80 feet, 150-160 feet, open hole 160-200 feet; water level Aug. 6, 1970 was 18.73 feet below land surface.

	Thickness (feet)	Depth (feet)
Alluvium:		
Sand, very fine to very coarse, angular to subrounded, and very fine to very coarse subrounded to rounded gravel; contains cobbles and red clay. Larger grains are mostly red argillite and light-brownish-red quartzite	12	12
Sand, very fine to very coarse, angular to subrounded, and light-red clay; contains very fine to coarse gravel and a few cobbles	21	33
Sand, very fine to very coarse, angular to subrounded; contains light-red clay and very fine to medium gravel	5	38
Gravel, very fine to medium, angular to subrounded and very fine to very coarse sand; contains light-red clay. Gravel is mostly black fine-grained igneous rock	6	44
Gravel, very fine to medium, angular to subrounded and medium to very coarse sand. Gravel is mostly black fine-grained igneous rock	4	48
Gravel, very fine to medium, angular to subrounded, and very fine to very coarse sand; contains layers of sandy clay. Gravel is mostly black fine-grained igneous rock	32	80
Tertiary(?) sediments:		
Clay, silty, light-yellow-brown; contains layers of very fine to very coarse angular to subrounded gravel and very fine to very coarse sand. Gravel is mostly argillite and limestone	16	96
Clay, sandy, gray, and thin layers of medium to very coarse sand; sand is mostly grains of quartz and volcanic glass; contains abundant euhedral crystals of pyrite and fragments of chert	36	132
Gravel, fine, well-rounded, and very fine to medium sand; contains light-gray clay. Gravel is mostly argillite and a fine-grained black igneous rock	2	134
Clay, light-bluish-gray, and layers of very fine to coarse subrounded to rounded sand. Sand contains chert, argillite, and sandstone pebbles. Clay contains abundant euhedral crystals of pyrite. A thin black film forms on top of drilling mud	66	200

15N6W20cba. The Anaconda Company test hole WO-2; land surface elevation 5,145.09 feet; perforated 6-20 feet, 50-63 feet; water level June 13, 1970 was 3.28 feet below land surface.

	Thickness (feet)	Depth (feet)
Fill	2	2
Sand, silty; brown; sand is fine to very coarse, subangular to subrounded argillite; poor aquifer.	4	6
Sand, gravelly, minor silt; brown; sand is fine to very coarse grained, subangular to subrounded varicolored argillite; loose, very clean; excellent aquifer, couldn't bail down	14	20
Gravel, sandy, silty, clayey; light brown; gravel is fine argillite fragments; dense, no water	12	32
Silt, clayey, sandy; gray brown; silt is very firm; sand is mostly fine grained with scattered fine gravel; no water	9	41
Gravel, sandy, silty, clayey; brown; gravel is fine subangular argillite; clay becomes stiffer and more abundant with depth; poor aquifer, may yield 5-20 gpm	19	60
Bedrock, diorite porphyry; dark gray; could be gravel to 65 feet	5	65

15N6W20daa. The Anaconda Company test hole WC-1; land surface elevation 5,202.14 feet; perforated 26-31 feet, 42-48 feet; water level 4.78 feet below land surface.

	Thickness (feet)	Depth (feet)
Sand and gravel, silty, clayey; light-brown; sand is fine to very coarse grained; gravel is fine to coarse, flat and angular argillite; dense; poor aquifer	15	15
Sand, fine gravel, silty, clayey; light brown; sand is fine to coarse; gravel is mostly pea size, subangular argillite and becomes coarser with depth; fair aquifer	15	30
Clay, sandy, silty; blue-gray; clay is firm; impermeable	5	35
Sand, fine gravel, silty, clayey; light-brown; sand is fine to very coarse grained; dense; no water	5	40
Sand and gravel, minor silt; yellow-brown; sand is medium to very corase; gravel is fine; sub-angular to subrounded quartzite and argillite; loose, clean; excellent aquifer	7	47
Sand and gravel, silty, clayey; yellow-ochre; clay is firm; no water	6	53
Bedrock, yellow-ochre; oxidized and weathered argillite, clayey	0	53

15N6W21cba. The Anaconda Company test hole WO-3; land surface elevation 5,200.96 feet; perforated 45-75 feet; water level June 16, 1970 was 0.25 feet below land surface.

	Thickness (feet)	Depth (feet)
Soil, sand, silty, clay.....	5	5
Gravel, sandy, silty, clayey; light-brown; gravel is fine argillite fragments; dense; poor aquifer.....	16	21
Gravel, sandy, minor silt and clay; light-brown; gravel is poorly sorted, fine- to medium-grained argillite fragments; medium dense; fair aquifer.....	14	35
Sand, gravelly, silty, clayey; yellow-ochre; sand is medium to very coarse grained; gravel is fine, subangular to subrounded argillite; dense no water.....	10	45
Sand, gravelly, minor clay and silt; yellow-ochre color; sand is medium to very coarse grained; gravel is fine, subangular argillite fragments; medium dense; good aquifer.....	17	62
Sand, minor silt; gray-brown; sand is fine to very coarse grained subangular to subrounded diorite and pyrite, poorly sorted, loose; good aquifer.....	10	72
Bedrock, diorite, gray; contains abundant pyrite.....	4	76

15N7W16ccc. U. S. Geological Survey test hole B-1; land surface elevation 5,139.13 feet; perforated 35-41 feet, 58-63 feet; water level Aug. 14, 1970 was 26.74 feet below land surface.

	Thickness (feet)	Depth (feet)
Topsoil:		
Silt, sandy, black; contains a few angular to rounded pebbles	4	4
Till:		
Clay, sandy, light-pink; contains a few angular to well-rounded pebbles and cobbles of limestone, argillite, and quartzite	33	37
Gravel, very fine to very coarse, angular to subrounded, and fine to very coarse angular to subrounded sand; contains clay and cobbles. Larger grains are mostly red argillite and light-pink quartzite. (Water level rose to about 25 feet below land surface)	5	42
Sand, very fine to very coarse, angular to subrounded; contains lifht-pink clay, cobbles, and boulders	18	60
Gravel, very fine to medium, angular to subrounded, and fine to very coarse angular to subrounded sand; contains light-pink clay. Larger grains are mostly argillite, limestone, and quartzite	2	62
Clay, sandy, light-pink; contains a few pebbles and cobbles	35	97
Basement rocks(?):		
Argillite, light-purple. Unable to drill further, could be a boulder	1	98

15N7W21cbb. U. S. Geological Survey test hole B-2; land surface elevation 5,089.87 feet; perforated 105-110 feet, open hole 160-263 feet; water level Aug. 25, 1970 was 24.04 feet below land surface.

	Thickness (feet)	Depth (feet)
Till:		
Clay, light-pink; contains pebbles, cobbles, and very fine to very coarse angular to subrounded sand. Larger grains are mostly quartzite, argillite, and limestone	105	105
Gravel, very fine to fine, angular to subrounded; contains medium to very coarse sand. Gravel is mostly yellow limestone, red argillite, and quartzite	5	110
Clay, light-reddish-brown; contains fine to very coarse sand, and a few quartzite cobbles. Sand grains are mostly argillite and limestone	9	119
Tertiary(?) sediments:		
Clay, light-yellowish-brown, and medium to very coarse, subrounded to well rounded sand; contains thin layers of blue-gray clay. Larger grains are mostly argillite and limestone	9	128
Clay, bluish-gray, sticky, contains very fine sand	10	138
Sand, medium to very coarse, subrounded to rounded--composed of argillite and limestone grains	2	140
Clay, light-bluish-gray, and very fine to medium angular to subrounded sand. Sand is mostly quartz and an unidentified black rock	2	142
Gravel, very fine to coarse, subrounded to well-rounded; contains medium to very coarse sand. Gravel is mostly argillite, limestone, and unidentified igneous rocks	2	144
Clay, sandy, light-yellowish-brown; contains very fine to fine well-rounded gravel. Gravel is argillite, limestone and diorite	16	160
Clay, bentonitic, reddish-brown; contains sub-angular clear volcanic glass shards and angular grains of an unidentified black rock	75	235
Clay, lavender; contains very fine to very coarse angular to subrounded sand. Sand is composed of black unidentified rock, limestone, dark-gray argillite and clear grains of volcanic glass	28	263

15N7W23dcc. U. S. Geological Survey test hole C-1; land surface elevation 5,093.21 feet; perforated 107-117 feet; at completion of drilling Aug. 24, 1970 test hole was dry, on Oct. 20, 1970 water level was 70.13 feet below land surface.

	Thickness (feet)	Depth (feet)
Till:		
Clay, light-red, and very fine to very coarse angular to subrounded sand; contains very fine to very coarse gravel and a few cobbles. Cobbles and gravel are mostly argillite, limestone, and quartzite.....	121	121
Basement rocks(?):		
Limestone, dolomitic, dark-gray. Unable to drill further, could be a boulder.....	1	122

15N7W23dcc2. U. S. Geological Survey test hole C-2; land surface elevation 5,058.30 feet; open hole 20-105 feet, water level Aug. 26, 1970 was 4.87 feet below land surface.

	Thickness (feet)	Depth (feet)
Topsoil:		
Silt, sandy, dark brown; contains gravel and cobbles.....	4	4
Alluvium:		
Clay, light-gray, and fine to very coarse sand; contains cobbles and boulders.....	11	15
Till:		
Clay, sandy, light-red; contains cobbles and subrounded to well-rounded medium to very coarse gravel. Gravel and cobbles are quartzite, argillite, and dolomitic limestone.....	72	87
Lakebed deposits:		
Silt, clayey, light-pinkish-gray, thinly bedded; contains thin layers of very fine sand.....	18	105

15N7W24abc. The Anaconda Company test hole WO-1; land surface elevation 5,083.11 feet; perforated 15-40 feet, 80-90 feet, 124-126 feet; water level June 12, 1970 was 5.94 feet below land surface.

	Thickness (feet)	Depth (feet)
Gravel, sandy, clayey; brown; gravel is fine angular to subrounded, varicolored argillite; medium dense; poor aquifer.....	28	28
Sand, fine gravel, minor silt; light-brown; sand is fine to very coarse grained, subangular to subrounded quartzite and argillite; loose, fairly clean; heaving sand, excellent aquifer.....	18	46
Clay, silty, scattered sand and gravel; light-brown; clay is stiff; drills open hole; no water.....	30	76
Gravel, sandy, minor silty; light-brown; sand is fine to very coarse; gravel is mostly fine; subangular to subrounded argillite; fair aquifer....	14	90
Gravel, sandy, clayey; yellow-brown; gravel is fine to coarse (1 inch) argillite fragments; dense clay is yellow and red (stiff); no water.....	7	97
Clay, gravelly; yellow-ochre; clay is very stiff; gravel is fine to pea-size yellow argillite; impermeable.....	15	112
Bedrock, argillite, blue-gray.....	14	126

15N7W24baa. The Anaconda Company test hole WO-4; land surface elevation 5,075.04 feet; perforated 15-40 feet, 86-105 feet, 108-110 feet; water level June 18, 1970 was 2.05 feet below land surface.

	Thickness (feet)	Depth (feet)
Soil	2	2
Sand, silty, clayey; brown; sand is very fine to medium grained with scattered fine gravel; dense, no water	7	9
Gravel, sandy; brown; sand is medium to very coarse grained; gravel is fine, flat subrounded argilite (red, yellow, green); gravel becomes increasingly finer and siltier from 30 to 57 feet; excellent aquifer	48	57
Clay, silty; brown; clay is very stiff; impermeable	25	82
Gravel, sandy, minor silt; brown; sand is fine to very coarse grained; gravel is fine, varicolored argillite becoming increasingly coarser and cleaner with depth; excellent aquifer	26	108
Bedrock, argillite, pale yellow; (drilled open hole)	10	118

15N7W27abc. The Anaconda Company test hole WO-6; land surface elevation 4,995 feet; no water.

	Thickness (feet)	Depth (feet)
Soil	2	2
Gravel, sandy silty, clayey; gray-brown; sand and gravel is mostly fine to coarse subangular argillite fragments; contains boulders; dense, no water	15	17
Bedrock, argillite, light-gray	5	22

15N7W27bda. The Anaconda Company test hole WO-5; land surface elevation 4,980.27 feet; perforated 15-23 feet, 55-60 feet, 65-70 feet, 82-86 feet; water level June 21, 1970 was 38.46 feet below land surface.

	Thickness (feet)	Depth (feet)
Soil	2	2
Gravel, sandy, silty, clayey; brown; gravel is fine argillite and quartzite; dense; no water	7	9
Gravel, sandy, silty; brown; gravel (same as above) contains large boulders; poor aquifer	19	28
Gravel, sandy, silty, minor clay; reddish-brown; gravel is argillite and quartzite fragments; contains boulders below 42 feet; dense, no water; drills open hole	29	57
Sand, silty, gravelly, minor clay; brown; sand is very fine to very coarse grained; gravel is fine (abundant altered pieces of granitic rock--quartz, feldspar, mica); medium dense; fair aquifer	28	85
Bedrock, dacite agglomerate?	9	94

15N7W28abb. U. S. Geological Survey test hole B-3; land surface elevation 5,032.32 feet; perforated 122-129 feet; water level Aug. 19, 1970 was 1.32 feet below land surface.

	Thickness (feet)	Depth (feet)
Outwash:		
Clay, light-pink; contains medium to very coarse angular to subrounded sand, cobbles, and boulders	35	35
Till:		
Clay, light-brownish-red; contains medium to very coarse angular to subrounded sand and a few cobbles. Cobbles are argillite and quartzite	88	123
Basement rocks:		
Diorite; contains hornblende, and plagioclase feldspar. Upper 5 feet are weathered and fractured, lower 2 feet are firm and drill slowly	7	130

15N7W28dcb. The Anaconda Company test hole WB-3; land surface elevation 4,957.64 feet; perforated 94-98 feet; water level June 20, 1970 was more than 12 feet above ground surface.

	Thickness (feet)	Depth (feet)
Soil.....	3	3
Gravel, clayey, sandy, silty; brown; gravel is fine to coarse grained, subrounded argillite and quartzite; clay is firm, dense; no water.....	8	11
Sand, silty, fine gravel; brown; sand is fine to very coarse; poorly sorted; poor aquifer.....	2	13
Sand, clayey, silty, fine gravel; pale red-brown; sand is very fine to very coarse grained; gravel is fine, subangular to subrounded quartzite and argillite; clay is firm; no water.....	19	32
Sand and gravel, minor silt; brown; sand is fine to very coarse grained; gravel fine to coarse; fair aquifer.....	3	35
Sand, clayey, silty, scattered fine gravel; pale red brown; sand is very fine to very coarse grained; poorly sorted, dense; clay is firm, may be intermittent stiff clay layers; no water.....	45	80
Gravel, sandy, minor silt; brown; gravel is fine to coarse (becoming larger with depth), subrounded to rounded quartz and argillite (to 1 inch); sand is medium to very coarse grained quartz, argillite; excellent aquifer.....	18	98

15N7W33dcb. The Anaconda Company test hole WB-1; land surface elevation 4,876.51 feet; perforated 24-30 feet, 55-68 feet, 80-100 feet; water level June 15, 1970 was 3.94 feet below land surface.

	Thickness (feet)	Depth (feet)
Gravel, sandy, silty, clayey; light-gray-brown; gravel is mostly fine with scattered rocks to 3 inches in diameter; poorly sorted; dense poor aquifer, enough water for drilling	24	24
Gravel, sandy, minor silt; light-brown; good aquifer	1	25
Sand, gravelly, silty; light brown; sand is very fine to coarse grained, subrounded argillite; gravel is fine subangular to subrounded, varicolored argillite; medium dense; fair aquifer	29	54
Gravel, sandy, silty; light-brown; poorly sorted; medium dense; good aquifer	16	70
Clay, silty, scattered fine gravel; light-red-brown; clay is firm, no water	5	75
Sand and gravel, light-brown color; sand is fine to medium grained, fairly well sorted, subrounded to rounded quartz; feldspar gravel is fine to coarse, argillite, fair to good aquifer	15	90
Sand and gravel, silty, clayey; brown color; sand is fine to very coarse; gravel is fine to coarse; poorly sorted; medium dense; no water	5	95
Sand and gravel, silty, clayey; pale-yellow-brown; gravel is fine (1/4 inch), angular to subangular argillite, quartzite; dense; no water	10	105
Oxidized bedrock, yellow-ochre color	12	117
Diorite, grayish-green; contains abundant pyrite	12	129

15N7W33dcd. The Anaconda Company test hole WB-2; land surface elevation 4,879.52 feet; perforated 20-83 feet; water level June 10, 1970 was 4.02 feet below land surface.

	Thickness (feet)	Depth (feet)
Sand and gravel, silty, minor clay; brown color; sand is fine to very coarse, subangular quartzite and argillite; gravel is mostly fine angular to subangular quartzite and argillite; some scattered broken rock; no water	13	13
Sand, silty, scattered fine gravel; light-brown; sand is fine to coarse grained; good aquifer	7	20
Sand and gravel, minor silt and clay; light-brown; sand is fine to coarse grained, gravel is fine to one-half inch, angular to subangular quartzite and argillite; medium dense; good aquifer	25	45
Gravel, sandy, silty, minor clay; light-brown; gravel is fine to coarse subangular to subrounded argillite; medium dense; good aquifer	40	85
Gravel, sandy, silty, clayey; pale yellow brown; gravel is fine angular argillite; very dense; poor aquifer	17	102
Bedrock, argillite, clayey (weathered), pale-red and yellow	6	108

Table 8 -- Records of pump tests.

14N7W5cac. U. S. Geological Survey test hole A-1; land surface elevation 4,821.39 feet; perforated 61-71 feet, open hole 73-76 feet. Water level Oct. 16, 1970 at beginning of test was 29.25 feet below the top of the casing which is 1.50 feet above land surface. Average pumping rate was 90 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
1	1.70
2	1.70
3	1.79
4	1.79
5	1.79
6	1.78
8	1.79
10	1.80
12	1.79
15	1.81
20	1.82
25	1.84
30	1.80
40	1.75
50	1.77
60	1.87
70	1.85
80	1.85
100	1.79
120	1.77
150	1.84
200	1.83
250	1.84
300	1.90
1,350	1.95

14N7W5cda. U. S. Geological Survey test hole A-2; land surface elevation 4,817.43 feet; perforated 40-50 feet, 60-75 feet, 85-95 feet, open hole 100-160 feet. Water level Oct. 15, 1970 at beginning of test was 25.36 feet below top of casing, which is 1.70 feet above land surface. Average pumping rate was 92 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
1	0.69
2	.74
3	.74
4	.74
5	.74
6	.75
8	.78
10	.80
12	.79
15	.79
20	.74
25	.79
30	.81
40	.80
50	.82
60	.84
70	.85
80	.84
100	.85
120	.85
150	.86
200	.86
250	.84
330	.87
495	.84
1,055	.89
1,130	.94

14N7W5cdd2. U. S. Geological Survey test hole A-4; land surface elevation 4,814.39 feet; perforated 40-50 feet, 60-80 feet, 150-160 feet, open hole 160-200 feet. Water level Oct. 14, 1970 at beginning of test was 20.30 feet below top of casing, which is 1.10 feet above land surface. Average pumping rate was 90 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
1	1.80
2	1.90
3	1.85
4	1.80
5	1.80
6	1.80
8	1.80
10	1.80
12	1.80
15	1.80
20	1.85
25	1.85
30	2.00
40	2.10
50	2.10
60	2.19
70	2.10
80	2.10
90	2.10
100	2.10
120	2.10
150	2.05
200	2.07
300	2.05
400	2.07
610	2.07
1,125	2.10
1.245	2.10

Time since pumping stopped (minutes)	Residual drawdown (feet)
1	0.45
2	.35
3	.35
4	.33
5	.33

15N6W20cba. The Anaconda Company test hole WO-2; land surface elevation 5,145.09 feet; perforated 6-20 feet, 50-63 feet. Water level June 20, 1970 at beginning of test was 4.28 feet below top of casing, which is 1.5 feet above land surface. Average pumping rate was 80 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
1	4.38
2	4.96
3	5.06
4	5.15
5	5.54
10	5.62
15	5.98
20	6.68
25	7.42
31	8.02
40	8.86
50	9.26
70	9.26
82	9.55
100	9.76

15N6W20daa. The Anaconda Company testhole WC-1; land surface elevation 5,202.14 feet; perforated 26-31 feet, 42-48 feet. Water level June 17, 1970 at beginning of test was 4.78 feet below land surface elevation. Average pumping rate was 150 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
0.5	2.40
1	3.60
2	3.54
3	3.63
4	3.77
7.5	3.92
10.5	4.14
15	4.40
25	4.60
27	4.93
30	4.93
46	7.16
60	7.85
75	7.65
93	6.70
96	8.33
105	8.94
125	9.37
170	9.80
240	10.70
300	10.53
365	10.60

15N6W21cba. The Anaconda Company test hole WO-3; land surface elevation 5,200.94 feet; perforated 45-75 feet. Water level June 21, 1970 at beginning of test was 1.75 feet below top of casing, which is 1.5 feet above land surface. Average pumping rate was 145 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
1	9.19
2	14.12
3	15.67
6	32.85
10	34.71
15	35.61
20	36.08
30	37.00
45	37.70
60	37.80
120	37.89
180	37.89
240	37.89

15N7W24abc. The Anaconda Company test hole WO-1; land surface elevation 5,083.11 feet; perforated 15-40 feet, 80-90 feet, 124-126 feet. Water level June 24, 1970 at beginning of test was 7.44 feet below top of casing, which is 1.5 feet above land surface. Average pumping rate was 120 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
0.15	3.14
.60	4.88
1.20	5.31
2.65	5.62
3.54	5.78
8.45	5.87
10.20	5.94
20	6.07
30	6.07
60	6.07
120	6.07

15N7W24baa. The Anaconda Compant test hole WO-4; land surface elevation 5,075.04 feet; perforated 15-40 feet, 86-105 feet, 108-110 feet. Water level June 21, 1970 at beginning of test was 3.55 feet below top of casing, which is 1.5 feet above land surface. Average pumping rate was 150 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
0.15	1.65
.55	1.93
1	1.95
2	2.02
3	2.13
4	2.25
5	2.28
9	2.31
17	2.32
25	2.32
45	2.32
60	2.32
120	2.32

15N7W28abb. U. S. Geological Survey test hole B-3; land surface elevation 5,032.32 feet; perforated 122-129 feet. Water level Oct. 17, 1970 at beginning of test was 8.55 feet below top of casing, which is 1.45 feet above land surface. Average pumping rate was 83 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
1	7.64
2	8.11
3	7.60
4	7.60
5	7.65
6	7,80
8	7.87
10	7.95
12	8.11
15	8.35
18	8.50
20	8.60
25	8.70
30	8.88
40	9.15
50	9.43
60	9.65
70	9.80
80	10.00
90	10.24
100	10.37
120	10.66
150	10.95
200	11.49
270	11.98
300	12.13

15N7W33dcd. The Anaconda Company test hole WB-2; land surface elevation 4,879.52 feet; perforated 20-83 feet. Water level June 22, 1970 at beginning of test was 5.52 feet below top at casing, which is 1.5 feet above land surface. Average pumping rate was 140 gpm.

Time since pumping began (minutes)	Observed drawdown (feet)
0.7	2.68
1.5	3.08
2	3.28
3	3.58
5	3.88
8	4.18
10	4.38
15	4.62
22	4.81
25	4.91
30	5.07
40	5.24
50	5.48
60	5.54
90	5.54
120	5.54
180	5.54
240	5.54
300	5.54

Table 9. -- Relation of units of hydraulic conductivity, permeability, transmissivity, and flow.

(Equivalent values shown in same horizontal line)

Hydraulic Conductivity	Field Coefficient of Permeability
ft day^{-1}	gal day^{-1} ft^2
one	7.48
.134	one

Transmissivity	
ft^2 day^{-1}	gal day^{-1} ft
one	7.48
.134	one

Flow	
ft^3 sec^{-1}	gal min^{-1}
one	449
.00223	one